A Framework for Designing Energy Efficient Dwellings Satisfying Socio-cultural Needs in Hot Climates

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Declaration

This thesis is submitted to De Montfort University to fulfill part of the requirements of the degree of the Doctor of Philosophy in accordance with this institution rules and regulations. And I hereby declare to the best of my knowledge that the content of this thesis is my own work. Also, declare that the intellectual content of this thesis contains no material previously written or published by another person except where due reference is made.

Signed: ……………………………………………
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Approval

The undersigned certify that they have read and recommended to the Graduate School, De Montfort University for acceptance of the thesis entitled “A Framework for Designing Energy Efficient Dwellings Satisfying Socio-cultural Needs in Hot Climate” submitted by Nagah Ali in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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Abstract

Buildings are responsible for the largest share of energy consumption in the world. The effects of buildings on environment and people have generated interest especially in the developed world on how to reduce the significant energy consumption by the building subsector. Moreover, it shows the significance of the building sector in global efforts to reduce the effect of climate change and global energy consumption. The major challenge with buildings in countries in hot climates for example Libya is thermal discomfort especially in residential dwellings causing overdependence on mechanical cooling systems. Thermal discomfort and high-energy consumption in buildings are connected to socio-cultural factors and the approach to the design of residential buildings. Benghazi city, which is the second city and the capital of the eastern region of Libya has witnessed significant growth in population due to its economic prosperity and job opportunity. This has significantly increased the rate of construction of new dwellings and challenges with housing development. This research aims to produce a framework for designing energy efficient dwellings satisfying socio-cultural needs in a hot climate. The research adopted a mixed method approach to generate data that would guide the development of the proposed framework. Measurements and observation survey of 72 existing villas were conducted to determine climatic elements in and around buildings and to gather robust data on building elements. A questionnaire survey of 72 householders was conducted to generate data on the design of houses, open spaces, the perception of comfort and energy consumption in buildings. Moreover, 12 design professionals were interviewed to seek their opinions on the design of houses in terms of the social aspect and climate of Benghazi, the study context. Furthermore, a simulation study of a typical contemporary residential villa was conducted for a detailed investigation of the level of thermal comfort and energy consumption in existing buildings. All the data collected were analyzed using an appropriate method of analysis, which include Excel, content analysis and energy assessment tool, DesignBuilder. The findings showed that 51% of all the householders' surveyed were not satisfied at all with the level of privacy in their outdoor open spaces. In addition, design professionals' in the study area supported the need for a future sustainable housing development that placed emphasis on socio-cultural factors and the local climate. Further findings revealed that although the level of clothing for women was higher than men, women were comfortable at a higher temperature than men. Other findings showed that there are thermal discomfort and high-energy consumption in buildings due to the contemporary approach to the design of buildings that have little consideration for socio-cultural factors. Householders and design professionals agreed that energy efficiency could be achieved in buildings in the study context through the adoption of social and climatic design principles. The improvement measures conducted in the case study building showed 84% savings in terms of energy demand. The proposed courtyard design using the proposed framework led to a savings of 65% in terms of energy demand. Despite the high savings recorded and achieving the thermal comfort for the improved case study, it did not meet the privacy and other socio-cultural requirements for the study context. The prototype courtyard design did not satisfy comfort requirements using natural ventilation but met privacy demand by building occupants and can improve family cohesion among other benefits. Socio-cultural dimension is an important principle in sustainable buildings concept. Hence, it might be difficult for building users to be satisfied with a building that achieved energy target but failed to satisfy the occupant's requirements. Therefore, the prototype courtyard design was preferred for the study context despite its lower energy saving capacity. The prototype courtyard house confirmed the relevance and applicability of the proposed framework for promoting energy efficiency in buildings in hot climates, particularly in Benghazi. Moreover, important recommendations were made regarding selected areas for further research towards advancing this study.

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1.0 CHAPTER ONE: INTRODUCTION

1.1 Introduction

This chapter is structured into seven sections to provide a general introduction to this study. Section 1.2 presents background information about energy consumption in buildings and its effects. It highlights the importance of buildings, especially residential buildings in achieving energy efficiency in buildings since it is the higher consumption of world energy. Moreover, this section discusses how significant building occupants' behaviour is in decreasing buildings energy demand. Section 1.3 focuses on the statement of the research problem with the major emphasis on the challenges with housing development in Libya. Section 1.4 and section 1.5 present the research question and the research aim and objectives respectively. Section 1.6 centers on a brief overview of the research methodology and this chapter is concluded with the thesis structure in section 1.7.

1.2 The Background

The building sector consumes 40%, 16% and 25% of the world's energy, fresh water, and forests timber respectively (Ghiaus, 2004). Other researchers have stated that buildings are responsible for the largest share of energy consumption in the world compared with another economic subsector (Perez-Lombard, 2008). The energy consumed globally by buildings depend directly or indirectly on fossil fuels. Research has shown that the amount of fossil fuel consumed by buildings world over exceeds 74 million barrels per day (Roaf et al., 2009). These statistics have generated interest especially in the developed world on how to reduce the significant energy consumption by the building subsector. Moreover, it shows the significance of the building sector in the global efforts to reduce the effect of climate change and reduce global energy consumption. Ochedi et al. (2016) stated that significant energy consumption by buildings demands conscious efforts on adopting energy efficiency measures.

Petersen and Svendsen (2010) posited that building design process and energy performance of buildings have become relevant issues for designers due to the fact that the building sector accounts for the highest consumer of energy. Hyde (2012) is of the view that climate responsive design is key to reducing energy consumption by the building sector. Tzikopoulos et al. (2005) stated that energy effective construction approaches could reduce CO2 emission by 60% or more. Moore et al. (2013) show that energy-efficient design techniques alone can decrease energy consumption in buildings by 40% to 60%. This shows that a significant amount of energy reduction can be achieved through the appropriate design of buildings, especially residential buildings.

Several terms have been coined worldwide towards reducing energy consumption in buildings. This includes low carbon energy buildings, eco-houses, green buildings, energy efficient buildings, and ultra-low energy buildings. Low carbon buildings is an approach to reduce construction impact on the environment through appropriate design techniques. Other energy efficiency strategies are also connected to this goal. Low energy building can decrease buildings operation costs by up to 80% using integrated design techniques (EU, 2009).

Studies have shown that African countries are lagging behind in investment in energy efficiency measures. The most significant reason for this is a lack of institutional framework (Ebohon and Rwelamila, 2001). In addition, Du Plessis (2002) revealed that there is a lack of relevant policies and method in developing countries to decrease energy consumption in buildings.

Climate is an important factor to consider in the design of buildings towards reducing energy consumption. Moore et al. (2013) posited that climate is a relevant factor to consider for deciding on the techniques towards realizing energy efficiency in buildings. Hassan and Lee (2015) who seem to support this view stated that sustainability is a place dependent concept. Singh et al. (2007) opined that there are different climates in the world and each requires a suitable architectural solution. Therefore, it is important for designers to place significant emphasis on local climate in their efforts to decrease energy consumption by buildings.

Another relevant factor to consider in the design of energy efficient buildings is a socio-cultural factor. Woodcraft et al. (2011) show that sociological factors are significant to the achievement of sustainable housing development. Studies have shown that buildings occupants' behaviour plays a significant role in energy consumption by buildings (Wei et al., 2014; Pan et al., 2017; Gilani et al., 2018. Hong et al., 2016). Hong et al., (2016) stated that occupants' behaviour is among the most significant sources of uncertainty in the prediction of building energy performance using dynamic thermal simulation due to complexity and uncertainty in buildings' occupants' behaviour. Previous studies have shown that building occupants' behaviour can have a similar effect that mechanical cooling systems and appliances in terms of energy use (Haas et al., 1998; Van der Linden., 2006). Mahdavi et al. (2008) stated that good energy efficient building design and operational practice could lower energy use in buildings. The areas that occupants' behaviour has an effect on buildings' energy consumption include opening and closing of windows, turning on/off of electrical equipment, cooling, and heating systems and control of heating and cooling set points. A study by Hong and Lin (2013) revealed that modification of building occupants' behaviour could lead to savings of 5% to 30% of energy demand in buildings.

On the other hand, occupants' satisfied is one of priorities of sustainable design, which their physiological and psychological are necessarily linked and balanced (Amerigo and Aragones, 1997; Adriaanse, 2007; Steemers and Manchanda, 2010; Lee et. al., 2011). Comfort factors include both quantifiable parameters, (for instance, thermal comfort, natural ventilation, and natural lighting) and qualitative parameters (for instance, providing of privacy and personal control over the comfort of one's private space). All the previous factors interact and affect the way residents use a building, thus it necessary to be considered through designing of building (Gann et. al., 2003; Steemers and Manchanda, 2010).

Several researches confirmed that privacy and comfort of residents in buildings are considered as substantial attributes of achieving sustainability of buildings. In addition, building design can influence significantly to enhance the privacy and comfort of residents. However, there are different challenges to meet residents' satisfied in terms of the ability to control their own indoor and outdoor space (Amerigo and Aragones, 1997; Gann et. al., 2003; Adriaanse, 2007; kennedy et. al., 2015).

The discussion above confirmed that design professionals and building occupants have key roles to play in the efforts to decrease energy consumption by buildings. Moreover, it is evident that climate is an important factor to consider I the design of energy efficient buildings. Hence, this research considers the hot climate of Benghazi with aim of producing a framework for designing energy efficient dwellings satisfying socio-cultural needs. The researcher is of the view that this will improve thermal comfort, decrease energy consumption in buildings, and help to address socio-cultural problems associated with contemporary houses.

1.3 Research Scope

The Islamic religion has a great effect on housing design in traditional dwellings, Islamic society has generated an especial design for houses which the plan of the house was directed into inside with simple façade (external walls) to enhance visual privacy. Furthermore, climate design in traditional houses had a strong role to modify and moderate indoor temperature (El-Shorbagy, 2010). Also, climate completed the needs of privacy through its design elements, for example, windows were directed to inside into internal open space (courtyard), which help to provide a house with natural light with natural air ventilation (Susilawati and Al Surf, 2011).

Evidently, western design was imported to many Islamic countries, for example, in Libya Italian colony established a new housing design regarding housing development. However, this development has not met the social-cultural requirements as an Islamic country (Al Sayyed, 2012), it has essential principles which should be considered as well as climate conditions. After 1969, Libyan government started to construct a new and large houses projects to meet the increasing demand for houses without understand the social-cultural needs and climate conditions in Libya. Although privacy is one of important requirements in Islamic houses, it is ignored in most of contemporary houses as, discussed by (Nabavi and Goh, 2011; Mahgoub, 2003; Ajaj and Pugnaloni, 2014; Almansoori, 2012). Furthermore, local climate has a great impact of the strategy of design and form of a building (Khoukhi and Fezzioui 2012; Leylian, et al. 2010; Salem et al. 2010; Khalaf, 2014), pointed out to the importance of study microclimate during the design process and they found contemporary Islamic houses lacking to climate design elements.

Although several projects have studied traditional houses and contemporary houses in hot climates, they have not investigated the Islamic cultural background in conjunction with climate. This is necessary to identify principles, which will contribute to achieving residents' needs and low energy consumption.

1.4 Statement of the research problem

The big desert constitutes about 95% of the land of Libya and characterized by a hot arid climate, which needs particular design considerations and influenced the coastal region (Abdel-Galil, 2012). According to Chojnacki (2003), Libya has been under many changes in economic, cultural and political issues leading to a considerable transformation in dwelling forms (Chojnacki, 2003). These buildings lacked the socio-cultural features of the traditional buildings and were not designed based on the local climate.

The adoption of western design and construction approach led to some challenges with building development in the entire Libyan cities. One of these is the lack of socio-cultural features in the contemporary houses. Several authors have argued that the spatial configuration of contemporary houses does not satisfy the traditional pattern of family life and the demand for daily living by the people. Some of the problems associated with contemporary houses include lack of privacy, noise and insufficient size of spaces for family activities (El-Fortia, 1989; Emhemed, 2005; Amer, 2007). El- Menghawi (2004) attributed the challenges with contemporary houses to the effect of westernization, which is gradually changing the appearance of Libyan cities. One of the objectives of this study is to reduce socio-cultural challenges associated with contemporary dwellings in Libyan cities, especially in Benghazi.

Another challenge with the contemporary houses is that there were not designed based on the local climate. Therefore, people do not always feel comfortable in their houses. All contemporary houses depend on mechanical cooling systems to achieve thermal comfort in houses, especially during the summer months. This has led to huge energy consumption by residential dwellings in Libyan cities (Shawesh, 2000; Almansori, 2010; Gabril, 2014).

Benghazi is the second largest city in Libya and has a population of about 631,555. It is the capital of the northern region and has the highest population density of nearly 2000 people per square kilometer (Agll et al., 2014). The growth in the population of Benghazi due to its economic prosperity and job opportunity has led to a corresponding increase in housing demand (Mohammed, 2013). Moreover, the increase in population has significantly increased the rate of construction of new dwellings leading to an increase in energy consumption by buildings. Apart from this, there are serious challenges with the housing development in the entire Libya and Benghazi in particular. Some of these challenges are socio-cultural while others are related to thermal comfort and energy consumption in buildings, particularly residential dwellings.

Islamic religion, which is practiced by about 97% of the population of Libya, has marked effect on the design of traditional buildings. Cultural characteristics, which relates to people's behaviour and social interactions is a key aspect of building design (Emhemed, 2005). The major aim of the design of buildings and the urban pattern is on the need for privacy and to establish a common bond within the society. Moreover, traditional buildings were designed and constructed with local building materials and construction techniques that help to modify and moderate indoor temperature (El Shorbagy, 2010). A common element of the traditional architecture is the courtyard, which helps to improve privacy, natural lighting, and ventilation (Susilawati and Al Surf, 2011). Hence, traditional houses in Libyan cities are well adopted to the local climate.

The discovery of oil in the 1960s led to rapid socio-economic changes at various level, especially in a housing development (Azzouz, 2000). This development brought about the public sector and private sector housing and other contemporary residential styles, which were designed and constructed majorly with modern building materials. Al-Jokhadar and Jabi (2016) posited that the contemporary dwellings are usually in high-rise blocks and detached houses. The western approach to the design of houses did not consider socio-cultural requirements (Azzouz, 2000). Privacy which is an important aspect in the design of dwellings was ignored in most contemporary houses (Mahgoub, 2004; Nabavi and Goh, 2011; Almansori, 2012; Ajaj and Pugnaloni, 2014). Gabril (2014) stated that the contemporary houses have outdoor spaces instead of the traditional courtyard, which were used in traditional houses. Moreover, the buildings were characterized by wide glass windows, concrete and steel elements. The design and construction of the contemporary houses did not really consider the local climate. El Shorbagy (2010) stated that local climate and energy-related issues, which are important factors, were not considered in the contemporary design of dwellings.

The adoption of contemporary style has led to increased thermal discomfort in buildings making building occupants depend more on mechanical cooling systems among other challenges. UN Statistics Division/CDIAC report in 2006 ranked Libya as the 11th country in the world in terms of CO2 emissions per person, with 1.98 tonnes per capita, which is higher than the global average of 1.13 tons per year (Gabril, 2014). Figure 1-1 shows Carbon dioxide emission per capita, MAG indicator for different countries.

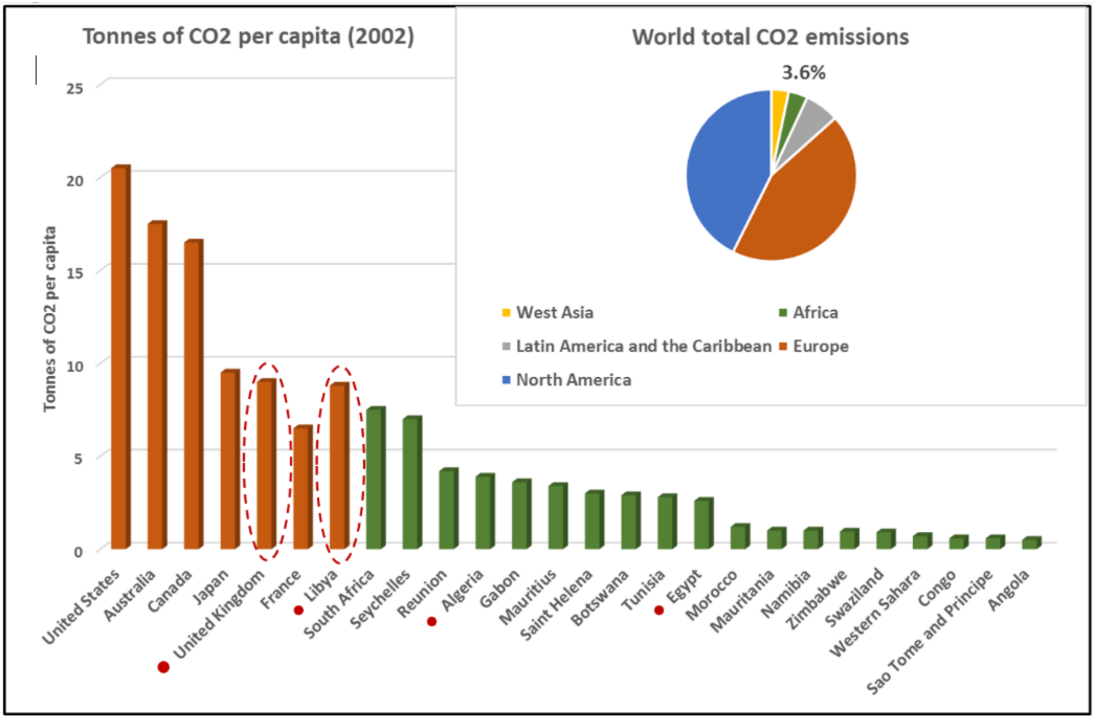

Figure 1-1 Carbon dioxide emission per capita, MAG indicator.

Sources: UN statistics Division/CDIAC, carbon dioxide emissions per capita, MDG indicator 28, 2006, adapted from Gabril, (2014).

The highest energy consumption in Libya is due to cooling demand and domestic hot water and these accounts for about 39% of the total energy consumption (GECOL, 2012). Figure 1-2 shows energy consumption distribution in Libya.

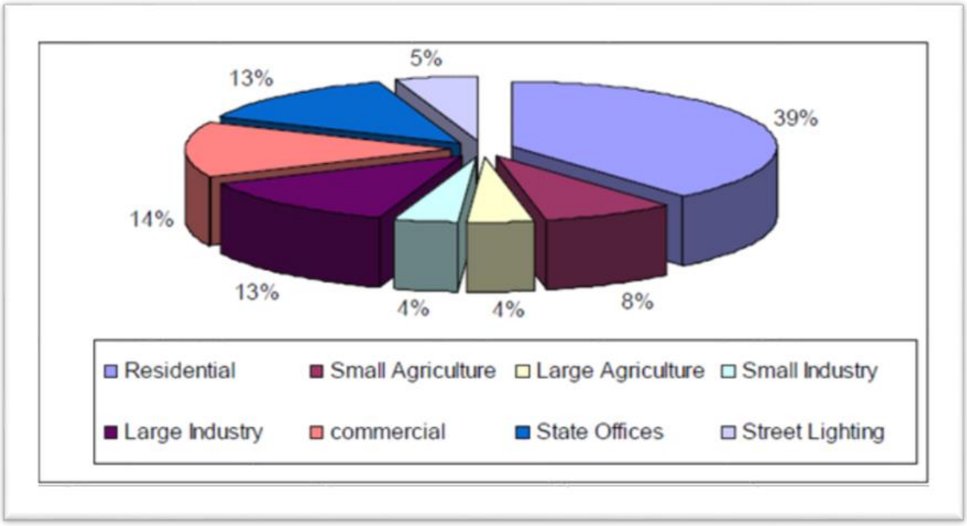

Figure 1-2 Energy consumption distribution in Libya.

Source: GECOL report 2012, Gabril, (2014)

The high level of energy consumption by buildings in Libyan cities points to the need to develop strategies to mitigate significantly this challenge. This research aims to contribute to the global efforts to reduce energy consumption by residential buildings hot climates, especially in Benghazi, Libya.

1.5 Research Questions

The need to improve comfort in buildings and to reduce energy consumption in dwellings form the basis of this research. The literature review in chapter 2 and the existing data on the study context presented in chapter 3 guided the researcher to produce the research questions for this study. Therefore, the research questions are:

1. How can designers produce dwellings that satisfy socio-cultural factors based on the local climate?
2. What are the relevant design principles for achieving energy efficiency in residential dwellings in hot climates?

1.6 Research Aim and Objectives

The overall aim of this research is to produce a framework for designing energy efficient dwellings satisfying social-cultural needs in a hot climate. The following research objectives have been identified toward achieving this aim.

1. To assess socio-cultural issues in contemporary private dwellings in Benghazi, Libya.
2. To evaluate the energy performance and environmental human comfort in extremely hot domestic dwellings in Benghazi, Libya.
3. To produce a framework for designing energy efficient dwelling in a hot climate.
4. To produce a prototype design for future contemporary housing development in Benghazi by using the framework.

1.7 Research Methodology

In order to achieve the aim and objectives of this research and draw a clear picture for determining and analyzing the problems, necessary data will be collected and discussed.

A mixed method approach involving both quantitative and qualitative methods have been adopted for the conduct of this research. The quantitative approaches involve measurements, observational survey, and questionnaire interview with householders and simulation study of an existing villa. On the other, the qualitative methods include an interview with professionals and a case study of existing house in Benghazi. All findings of previous methods with secondary data lead to produce a framework, which is tested by designing a prototype for context. Figure 1-3 shows the outline of the methodology for this study.

A detailed research methodology, which discussed the research method and the entire research processes are presented in chapter 4.

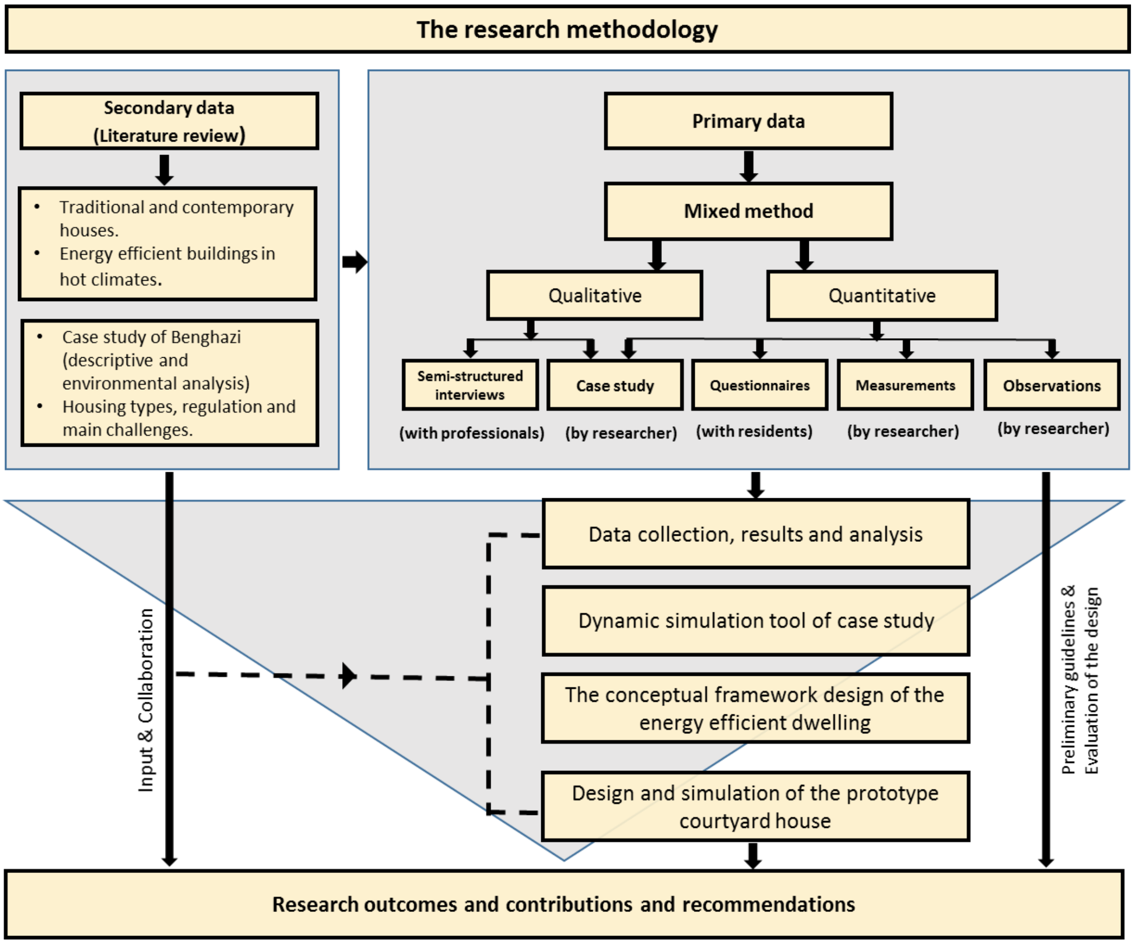

Figure 1-3 Diagram of methodology of the research

1.8 Thesis Structure

This thesis is structured into eight chapters, which are introduction, literature review, study context, research methodology, research data analysis, case study, discussion of findings, development, and testing of the framework and conclusion. Each of these chapters is discussed briefly under in the following subsection. Figure 1-4 outlines the structure of the entire thesis.

Chapter 1: Introduction

This chapter presents an overview of the whole thesis highlighting the research background and the major problems associated with residential buildings in Benghazi that informed this study. Other aspects of this chapter include the research questions, aim and objectives and an outline of the research method adopted.

Chapter 2: Literature review

This chapter is crucial to the thesis as it presents a critical review of existing literature regarding the research focus. The literature review covered sustainability in architecture, privacy and thermal comfort in traditional and contemporary houses in hot climates and energy efficient buildings.

Chapter 3: The study context

This chapter discusses the background information about Benghazi, which includes location, demographic and climatic data. It lays emphasis on the history of Benghazi traditional architecture, Libyan building regulation and the challenges with contemporary residential houses in Benghazi.

Chapter 4: Research methodology

An overview of research philosophy, the research philosophy adopted were presented in this chapter. Other aspects of this include a brief discussion on types of research methods, the method advocated for this study and the method of data collection and analysis.

Chapter 5: Research data analysis and discussion

This chapter deals with the analysis of primary research data involving measurements, observational survey and questionnaire interview with 72 householders. Measurement and observational survey of existing buildings were required to determine some climatic data and for a robust understanding of buildings elements. Questionnaire interviews with householders were aimed at good understanding building occupants' behaviour and respond to thermal discomfort in buildings. Moreover, interviews were conducted with three engineers and nine architects for information on the design and problems with contemporary private houses.

Chapter 6: Case study

This chapter presents a case study of the typical contemporary private residential villa from the study area. The simulation study of the chosen case study was conducted in two stages. First, the existing building was modeled and simulated using both natural ventilation and mechanical cooling system to determine its performance and compare their energy demand. Second, the existing villa was improved through the adoption of some energy efficient design principles. The energy demand of the improved villa using both natural ventilation and mechanical ventilation were compared with the existing buildings to determine possible differences.

Chapter 7: A framework for design of dwellings in hot climates

This chapter documents the discussion of the main findings from all the research data leading to the development of the framework for designing energy efficient dwellings satisfying socio-cultural needs in hot climates. The framework was then tested through a proposed design of a contemporary villa that incorporates courtyard and energy efficient design techniques.

Chapter 8: Conclusion

This chapter presents the summary of the entire thesis from chapter 1 to chapter 7. Moreover, it outlines the research contribution to knowledge, the research impact, recommendations areas for further research and limitations.

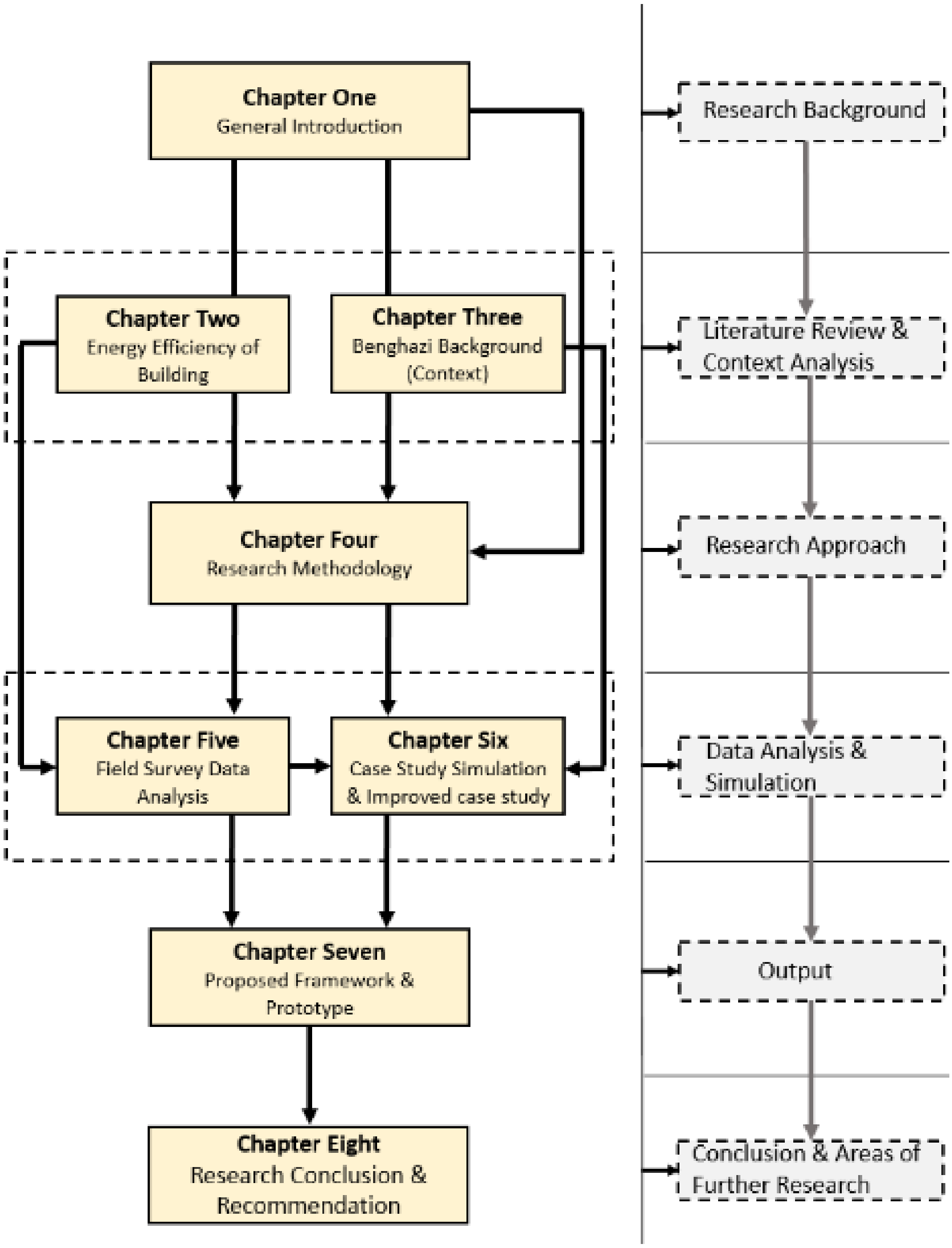

Figure 1-4 the thesis structure diagram

2.0 CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter presents a review of relevant subjects and concepts that are related to this study. The entire chapter is presented in nine sections. Section 2.2 discusses sustainability and sustainable architecture. Section 2.3 and section 2.4 centered on privacy dimension in traditional architecture and thermal comfort dimension of traditional architecture in hot climates respectively. Section 2.5 compares traditional and contemporary architecture in terms of privacy, thermal comfort, and energy consumption. Section 2.6 presented a brief discussion on energy efficient buildings. Section 2.7 gave an overview of thermal comfort while section 2.8 discusses the factors that affect energy consumption in buildings. This chapter was concluded with a summary in section 2.9.

2.2 Sustainability and sustainable architecture

2.2.1 Sustainability

The World Conservation Strategy of 1980 brought the idea of sustainability into the international discussion (IUCN, 1991). The concept of sustainability advanced and took a center stage in global environmental discourse in the Brundtland Commission report, which was organized in 1983 by the United Nations (Brundtland Commission, 1987). Kalan and Oliveira (2014) stated that sustainability has become the major concern of both government and non-governmental agencies, decision makers, international organizations, citizens and researchers. Shaw and Newby (1998, p.865) defined sustainability as “the capacity for continuance more or less indefinitely into the future.” Sustainability has also been defined as “the possibility that humans and other life will flourish on the Earth forever” (Ehrenfeld 2008, p.49). Researchers have different views on the concept of sustainability. Hence, there is a serious debate on the appropriate definition of sustainability. In this regard, Dresner (2012) stated that sustainability is a controversial concept due to the different meaning attached to it and its unlimited nature.

Despite the debate on what sustainability is and what is not, the concept grew into another concept like sustainable development. The term “sustainable development”, which it was first created in the World Conservation Strategy report, which was published in 1980 by International Union of Conservation of Nature (IUCN) (Dresner, 2012). The report focused on a discussion involving world poverty because of inequality regarding access to land for food and crop production, especially in developing countries (IUCN, 1991). Researchers have offered different definitions of sustainable development (See Jacobs, 1995; Pezzoli, 1997). The most acceptable and frequently quoted definition was offered by Brundtland Commission, formerly known as World Commission on Environment and Development (WCED), which states, “Sustainable development is the development which meets the need of the present without compromising the ability of the future generations to meet their own needs.” (Brundtland Commission 1987, p.45). This definition of sustainable development has been referred to as the first politically satisfactory definition Dresner (2012).

Sustainable development aims to provide human basic needs without harm to the functioning of the natural system of existence (Martens, 2006). It is a concept that supports the human struggle for freedom, peace, and better condition of living and healthy environment (Martens, 2006). Sustainable development has advanced to include almost every field of human endeavor including architecture. Hence, sustainable architecture, which has a strong, link to this research. Architecture is a means of creating and expressing the relationship that exists between human and the natural and cultural environment (Bodart and Evard, 2011). Sherlock (1991) stated that the first step towards achieving sustainability is to reduce energy consumption in buildings and to design cities using compact approach, which will decrease the need for transportation. The next section presents discussions on sustainable architecture and its link to energy efficient buildings, which is the focus of this research.

2.2.2 Sustainable architecture

Sustainable architecture is a design approach that aims to reduce the adverse effects of buildings on the natural environment through the adoption of the efficient and moderate use of construction materials, development space, and energy. It is an approach to the production of buildings that focuses on creating a harmonious and lasting relationship between the site microclimate and building occupants (Martens, 2006). The main objective of sustainable architecture is in line with the goal of sustainability, which is to maintain ecological balance and provide an opportunity for all life forms to live and flourish (Iyengar, 2015). The sustainable architecture will no doubt help to significantly reduce the contribution of approximately 50% of the world total greenhouse gas (GHG) emissions from buildings. Ibrahim and Mohammed (2005) posited that sustainable architecture is a means of advancing sustainable development with a target on architectural issues. This involves the thoughtful, efficient and effective use of energy resources to produce buildings that satisfy human comfort requirements and have minimal effect on the natural environment. Bodart and Evard (2011) stated that the concept of sustainable architecture has been strengthened over the past four decades characterized by strategies for a better future of the earth. Edwards and Turrent (2000) stated that in the third millennium, the essential basis of the design of dwellings and neighborhoods is to live with the surrounding environment in a friendly way and architecture and urban design have a major role to play in the efforts to achieve sustainable buildings in any part of the world.

Sustainable architecture is connected to cultural and social aspects of communities. Kalan and Oliveira (2014) were of the view that sustainable architecture involves a sense of place and so has a link with social and cultural aspects of the community. Over the years, cultural identity and creative diversity have been recognized and publicized as an international agenda on a global with positive signs (Mahgoub, 2004). An earlier study by King (1980) revealed that social and cultural factors have more influence on the architecture of buildings and other structures than climate, technology, materials, and economy. Hence, socio-cultural factors are an integral aspect of sustainable architecture. This supports the consideration of the socio-cultural aspects of the study context in this research.

Energy efficiency in buildings is an important aspect of sustainable architecture. Kalan and Oliveira (2014) stated that sustainable architecture is dominated by energy efficiency strategies towards the better economic performance of buildings and the mitigation of the effects of climate change. The quest to reduce energy demand and consumption in buildings has led to the adoption of both passive and active technologies by designers, especially architects (DeKay and Brown, 2013). This study aims to contribute to the reduction of energy demand by buildings through the production of a framework for designing energy-efficient buildings in hot climates.

2.3 Privacy dimension in traditional architecture

In a traditional Muslim home, the teachings of the Quran are a source of privacy in Islamic societies, in each home, dwellers or residents with their family should feel with freedom, relax and unwind without any disturbance or pressure from outside (Mortada, 2003; Omer, 2012; Shabani et al., 2011).

Protecting home privacy is necessary for Islam to enhance a quiet and functional family organisation (Othman, Aird and Buys, 2015). In addition, privacy, in Muslim houses, is the key element which forms the house as designing the building plan, and using interior house spaces (Othman, Aird and Buys, 2015). There are major aspects of privacy in traditional houses (Mortada, 2003; Othman et al., 2015). They are:

a. Privacy between neighbours' dwellings.
b. Privacy between males and females.
c. Privacy between family members inside a home.
d. Individual privacy.

Figure 2-1 shows the four major aspects of privacy in traditional houses.

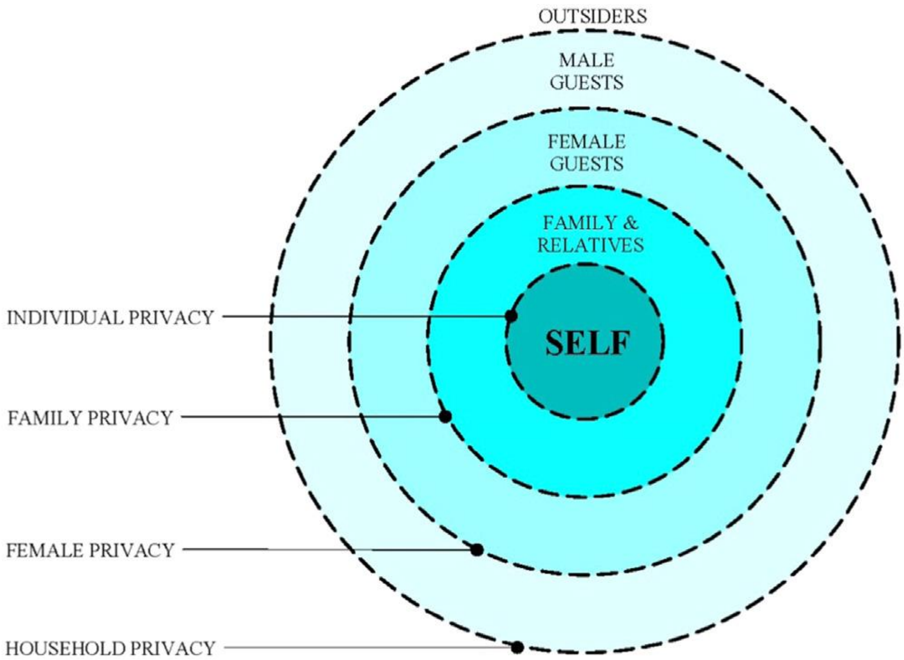

Figure 2-1 Layers of privacy in traditional home
Source: Othman et al., (2015)

Generally, requirements of privacy are met by precise design through providing the safety for the family and keeping the private life from the public world (Memarian et al., 2011).

a. Visual privacy (Visibility).
b. Acoustic privacy (noise transmission).
c. Olfactory privacy (odor control) (Hallak, 2003; Mortada, 2003; Sobh and Belk, 2011; Sobh et al., 2013)

2.3.1 Visual privacy

Visual privacy can be reached through the design of building envelope. This include the design and placement of entrance doors, the sizes and location of windows and other openings, the building heights and use of verandas. Other strategies involve the combination of provision of internal courtyards and the segregation of male and female spaces (Mortada, 2003; Othman et al., 2015). For privacy in terms of entrance doors to houses, entrance doors to building are not always located directly facing the main street. Moreover, entrance doors for two neighbours are designed not to face each other directly. In a situation where entrance doors are placed on the streets, they are alternated for houses that are directly opposite to enhance visual privacy (Bekleyen and Dalkiliç, 2011; Mortada, 2003; Othman et al., 2015).

2.3.1.1 Windows

In traditional homes, high consideration is given to the design and installation of external windows to ensure the achievement the visual privacy. Figure 2-2 shows an example of this in Saudi Arabia, which is similar to the study context. In Saudi, windows are placed based on the relationship between the indoor and outdoor floor levels. Where the interior level is approximately lower than the street level, the window sill can be less than 1.75m. On the other hand, if the street level is almost the same with the interior level, the window sill should be at least 1.75. The size of these windows are very small compared with windows in contemporary buildings (Mortada, 2003; Shraim, 2000; Al-Hussayen, 1999). Figure 2-2 shows traditional window height guidelines in Arabic cities. Furthermore, mashrabiya are used on external windows to improve privacy in indoor spaces (Mortada, 2003; Othman et al., 2015).

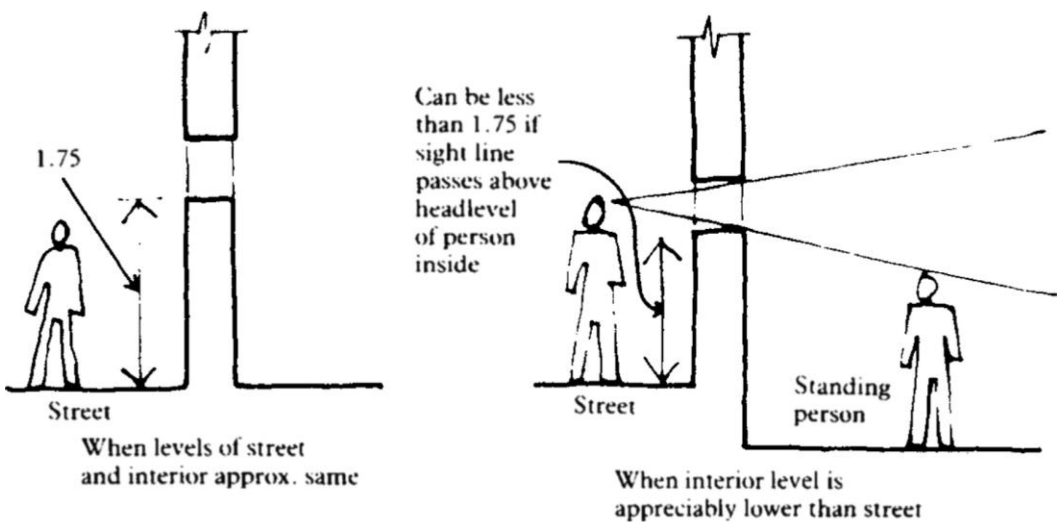

Figure 2-2 Traditional window height guidelines in Arabic cities

Source: Othman et al., (2015)

2.3.1.2 Housing heights

Control of building heights throughout the neighborhood is one of design methods to increase visual privacy (Mortada, 2003; Othman et al., 2015). In traditional houses, the heights of most buildings are the same to improve privacy between neighbours and to control visibility. If for instance, a two-floor building is next to one floor house, the side of the two floors building overlooking the one floor building will be built without windows to for visual privacy. For buildings with the same height, the positions of windows between buildings are alternative to improve privacy (Othman et al., 2015).

2.3.1.3 Courtyards

Courtyard is an essential feature of traditional houses. It helps to improve privacy with dwellings. In a courtyard house, there was separation between the male reception area and other family private areas. A direct access is provided from outside for male visitors into the male reception area to limit visual contacts into family spaces. The courtyard was used for family activities as a circulation spaces to other spaces. It was a place for playing, eating and sleeping during hot summer season. Moreover, the courtyard was used greatly for female social activities (Mahgoub, 2004). The courtyard provides privacy for family life and isolation from the public (Abarkan and Salama 2000). Courtyards in traditional houses are mostly built in square and rectangular shapes. Gedik (2004) stated that courtyard in old houses have square, rectangular and trapezoid plan and are always orientated in the east-west direction.

Courtyards in traditional houses were helpful in modifying the hot climate. It helps to minimise direct sunlight on buildings and provide shading to cool interior spaces. The shading provided in the courtyard makes it a good for family members to relax and carryout activities.

2.3.2 Acoustical privacy

Another significant principle of privacy is maintaining acoustical privacy in the design of traditional dwelling. This aims to shield the house uses from both external noise and noise between internal rooms by limiting sound transmission and vibration (Mortada, 2003).

Thick walls were used not just for decreasing the heat gain inside homes but also for ensuring acoustic privacy (Othman, Aird and Buys, 2015). Figure 2-3 shows the use of walls for acoustic privacy. In most of the traditional houses, thick layers of walls made of mud bricks, stones, and rocks were used to improve sound insulation (Mortada, 2003; Othman et al., 2015). In addition, the same design approach for walls were applied to floors and roofs to control the transmission of horizontal and vertical sound (Othman et al., 2015).

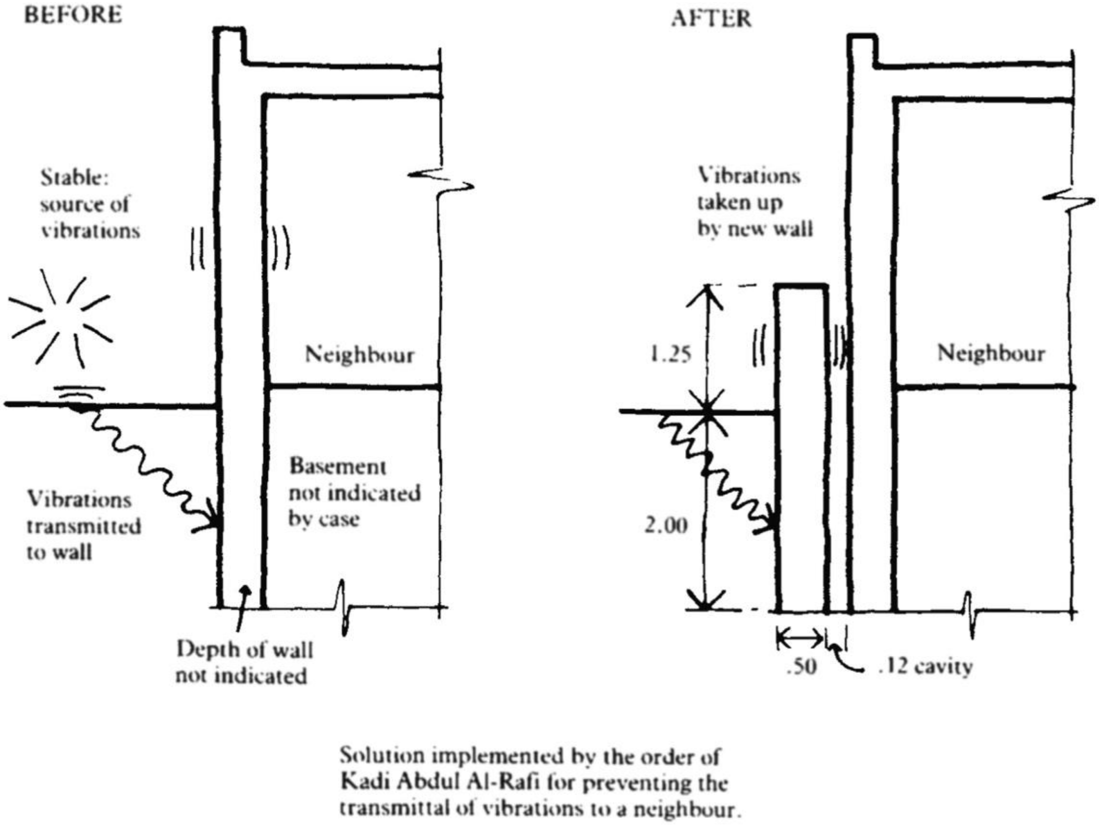

Figure 2-3 Example of thick external walls for optimum acoustical privacy
Source: Othman et al., (2015)

2.3.3 Olfactory privacy

Beside to visual and acoustical privacy in traditional houses, there is another type of privacy, which is termed olfactory privacy. The essential role of olfactory privacy is to control the spread of smell form the kitchen to spaces occupied by visitors and guests

(Sobh and Belk, 2011). In traditional houses incenses like woods or oud and incense stick were used to disinfectant for the control of smell (Sobh and Belk, 2011; Sobh et al., 2013).

2.4 Thermal comfort dimension in traditional architecture in hot climates

Traditional architecture principles can be used to overcome some challenges with contemporary houses in hot climates (Ajaj and Pugnaloni, 2014). These principles include compact form, building orientation, building envelope and materials, building components, natural ventilation, shading and passive cooling.

2.4.1 Compact urban form

Compactness is a planning principle that was adopted in traditional buildings to improve shading thereby enhancing comfort in buildings in hot arid zones. The compact system is a major characteristic of traditional city. The urban fabric of cities came from combining buildings into compounds. Hence, it is difficult to recognize the individual house. Buildings were connected to themselves in a compact manner to provide shading for one another and to shade narrow roads (Edwards et al., 2006). Ajaj and Pugnaloni (2014) stated that the compactness of the city helps to decrease the effect of sunlight, avoid sandstorms and reduce cooling demands. Compactness was necessary to minimise high solar radiation in hot climates. Figure 2-4 shows the compact arrangement of buildings in Kashan.

Figure 2-4 Narrow and irregular street in compact texture of Kashan
Source: Behbood et al., (2010).

2.4.2 Orientation

Correct orientation based on the movement of the sun is an important factor in the design of traditional houses. To achieve good building orientation, it is important for designers to understand the movement of the sun in both winter and summer in relation to the plan layout and section of buildings. Edwards et al., (2006) stated that in the past, building designers make us of empirical approaches to predict the movement of the sun. In recent times, architects make use of scientific methods to anticipate the impact of the sun on buildings in hot climates. According to Edwards et al. (2006, p.156), the projection angle can be determined through the following approaches:

a. The sunbeam angle "is the vertical angle between sunbeam and its horizontal shade".
b. ii) The azimuth angle "is the angular distance extending from the sunbeam shade to the north in a clockwise movement".

Figure 2-5 shows different spaces for family according to the direction of the sun on the ground floor of a house in Diyarbakir, Turkey.

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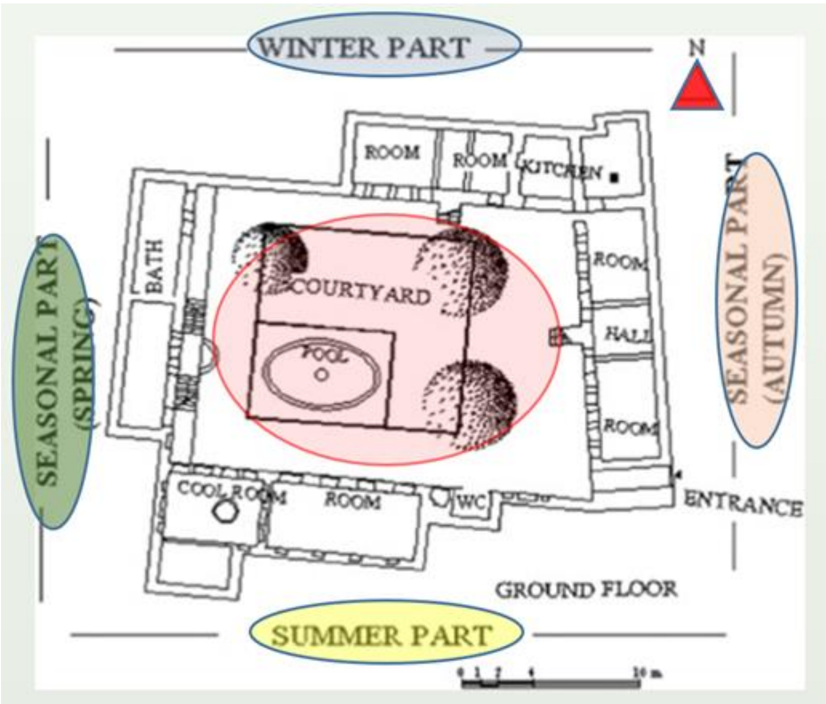


Figure 2-5 Different spaces for family according to direction of the sun, Ground floor plan of a home in Diyarbakir, Turkey
Source: Baran et al., (2011).

The sun projection angles change at different times through seasons. These provide the degree of solar penetration in many spaces of the house. Therefore, the best courtyards orientation is the east-west axis and longitudinal elevation. Figure 2-6 shows east-west axis orientation of courtyard.

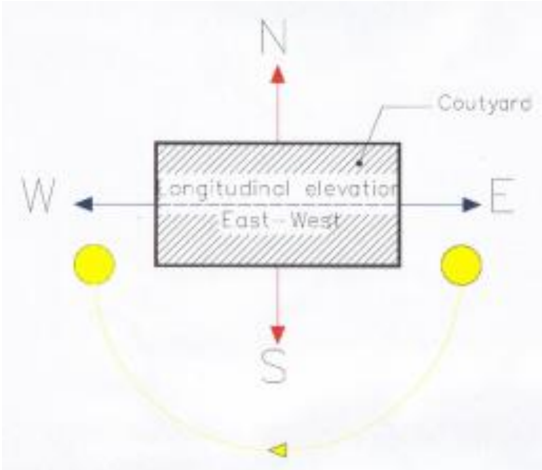


Figure 2-6 the orientation of the courtyard is longitudinal axis (East-West) for the sun movement.

In most courtyards, the lowest angle of sun projection is nearly 18° at 9 o'clock and 32.5° at 12 noon in mid-day in a winter season. This gives the maximum exposure of sunlight to be gained through the courtyard as Figure 2-7 (Edwards et. al., 2006).

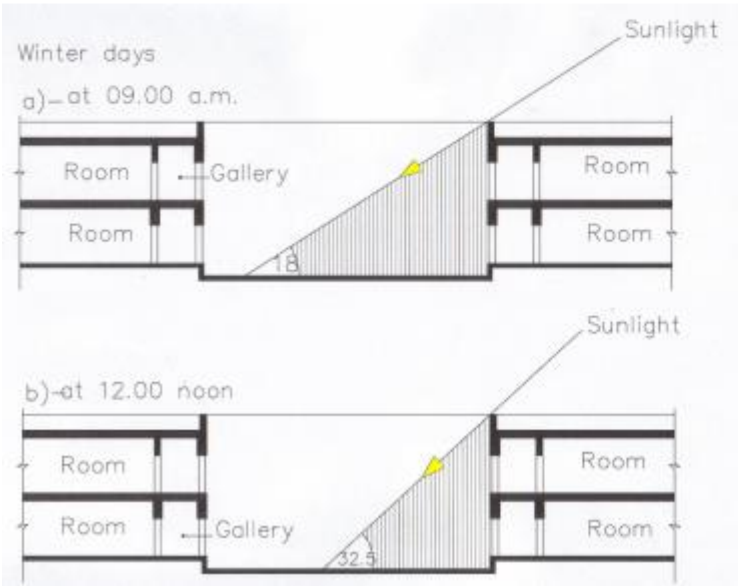


Figure 2-7 (a, b) the sun projection during winter days

Source: Adapted from Edwards et. al. (2006).

In summer the angle is approximately 72°, the height gives an effective shading of opening along the east-west axis, which is selected for the courtyard. Figure **2-6** shows the sun projection during summer days. Consequently, the orientation of courtyard can decrease the temperature indoors and outside from 46 °C to nearly 30 °C (Edwards et. al., 2006).

Figure 2-8 the sun projection during summer days
Source**:** adapted from Edwards et. al., (2006)

2.4.3 Building envelope and materials

In traditional houses, the building envelope helps to reduce the impact of the extreme climatic condition. Ajaj and Pugnaloni (2014) identified three functions of the building envelope that help to create cool indoor spaces. These are:

- Resisting the transference of heat
- Reflecting sun radiations
- Minimizing the heat and solar gain

In addition, indigenous building materials which were suitable for the climatic condition because of their physical properties and construction techniques were used for the construction of buildings. These materials include brick, stone, palm trunks and wood. They are reusable, recyclable, energy efficient and low in embodied energy. Hence, there are sustainable and help to improve thermal comfort in indoor spaces.

One of the principles in traditional houses is to encourage builders to use local materials because they act as thermal insulators especially when the widths of walls are thick with minimum external windows. Moreover, the solid external walls give privacy for inhabitants and reflect humility and social equity (Bekleyen and Dalkiliç, 2011).

2.4.4 Building components

Suitable construction can regulate the transfer of heat by thermal storage and time lag. The building components that can help in achieving this include openings, walls and roofs.

2.4.4.1 Openings

For natural lighting and ventilation, openings and windows are essential. However, in summer, the absence or the use of small openings can help to minimise heat gain, especially on the west side. The openings should be shaded away from direct sunlight and high on the walls to minimise the effects of ground reflection (Ajaj and Pugnaloni, 2014).

2.4.4.2 Walls

In summer days, heavy heat-storing materials were used to build walls of rooms which are used in daytime in living spaces, while rooms which are used during night times were built with walls having light heat capacity. Moreover, adequate shading was provided for rooms on the East and west directions to minimise heat gain. Also, for thermal and solar radiation, high reflective qualities are required (Ajaj and Pugnaloni, 2014).

2.4.4.3 Roofs

Flat roof is the most dominant roof types in tradition buildings in hot arid climates. Other types of roof shapes include domes and vaults. The construction of these roof types was purely based on local building materials and construction techniques. (Ajaj and Pugnaloni, 2014). These roof types helped to improve thermal comfort in interior spaces.

2.4.5 Natural ventilation

One of the passive cooling strategies in traditional architecture was natural ventilation. Natural ventilation can enhance indoor climate by evaporative cooling. In addition, orientation of traditional houses is based on the prevailing wind and sunlight. Therefore, solid facades are oriented toward the hot prevailing wind to protect the outdoor living spaces whereas allowing sufficient winter sunlight to enter the living areas. The main natural ventilation elements with courtyard are wind towers, malqafs. Figure 2-9 shows a section through a wind tower (malgafs) in Jeddah. The traditional malgafs in old Libyan cities are different from those in Jeddah shown but are based on the same concept of improving thermal comfort in indoor spaces. The design of wind towers can encourage airflow in house spaces (Bekleyen and Dalkiliç, 2011).

Figure 2-9 Wind towers, malqafs, Nassif house, Jeddah, 1974
Source: Fathy, (1986)

2.4.6 Shading

Solar radiation is a major source of heat gains in buildings. Adequate shading decreases air temperature, radiant heat and glare effectually. The most important ways for shading in traditional houses were by using protrusions and cornices on outer facades and on the inner courtyard walls (Ajaj and Pugnaloni, 2014). The amount of shade is determined by the size and shape of the building. In traditional dwellings, there was large area of shade because some parts of houses had more than one story thus the shaded area increases with the complexity level of housing design (Edwards et. al., 2006). Also, another important device for providing shading is Mashrabiya which has many significant functions such as:

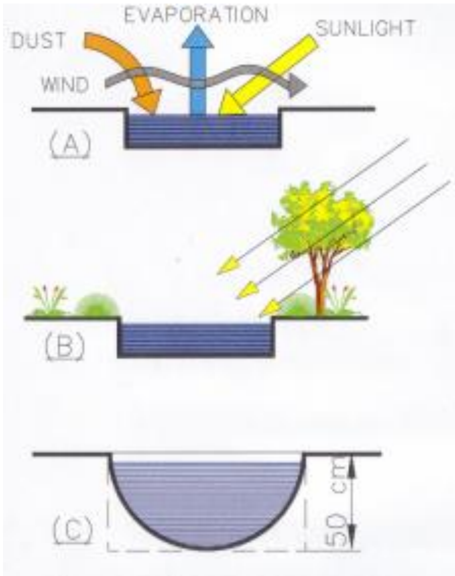
- Controlling the passage of light
- Controlling the air flow

- Decreasing the temperature of the air current
- Increasing the humidity of the air current and
- Ensuring privacy.

Masharabiya design is for filtering the direct sunlight to produce beautiful light and shade patterns by changing the sizes of the interstices (spaces between adjacent balusters) and the diameter of the balusters (Ajaj and Pugnaloni, 2014).

2.4.7 Passive cooling

In traditional house, besides the aesthetic view of water pool or fountain, there play important role in passive cooling (Bekleyen and Dalkiliç, 2011). The water pool occupies 30% of the garden area but this proportion depends on the garden area and the availability of water. Therefore, it differs from garden to garden. Water interacts with sunlight to produce evaporative cooling. Water canals which are narrow and deep in shape and approximately 50 cm in depth help to reduce surface evaporation. Figure 2-10 illustrates the used of water for cooling in courtyard houses. In addition, some water canals are made in a half-oval or rounded shape to discourage stagnant areas and to give the impression of more water than reality. Fountains and pools are located inside courtyard gardens and behind high walls for protecting the water from strong sandy winds that usually blow in Libyan areas (Edwards et. al., 2006).



(A)- Interaction of sun and water to produce evaporative cooling. (B)- Use of trees to prevent evaporation of scarce water. (C)- Use of deep canals to reduce surface evaporation and rounded shape to discourage stagnant areas.

Figure 2-10 Uses of water in courtyard housing

Source: adapted from Edwards et. al., 2006

2.5 Privacy and thermal comfort in contemporary houses

Researchers have studied and compared between traditional and contemporary houses in hot climate in terms of privacy, thermal comfort and energy consumption in houses (Mahgoub, 2004; Almansuri, 2010; Nabavi and Gohk, 2011; Khoukhi and Fezzioui, 2012; Ajaj and Pugnaloni, 2014). This section presents discussion on these factors.

2.5.1 Privacy

Privacy is a significant factor in the design of buildings in hot climates, especially in communities where the majority of the people practice Islam. Protecting the privacy of building occupants is necessary in traditional houses in these regions to enhance a quiet and functional family setting (Othman et al., 2015). Courtyard concept was adopted in the design of traditional buildings to achieve privacy. Mahgoub (2004) stated that courtyard design concept in traditional houses can be applied to modern houses to satisfy environmental and privacy needs. Khalaf (2012) posited that to achieve domestic privacy, the design of houses should carefully consider the transition from outdoor space to indoor spaces, building entrance and circulation. Amer (2007) and Almansuri (2010) recommended the use of small windows and shaded balconies to provide privacy in dwellings. They further stated privacy could be improved by using mashrabiya on windows and balconies. Concerning the placement of windows in houses, Khalaf (2012) stated that windows should be placed in a way that prevents direct visual access to interior spaces. This is aimed at improving the privacy needs of building occupants.

Salem et al. (2010) and Sharif et al. (2010) stated that contemporary buildings with their modern and extrinsic design have created social problems because buildings seldom follow inhabitants' lifestyles. Mahgoub (2004) revealed the reemergence of traditional courtyard concept in modern buildings due to socio-cultural and climatic factors and was of the view that more traditional architectural elements like small window will soon feature in modern buildings. This discussion seems to support the need for privacy in contemporary houses and how to improve privacy using design elements like courtyard and windows.

2.5.2 Thermal comfort and energy consumption

Thermal comfort is a very important factor in both traditional and contemporary houses. Apart from privacy need, another reason for the adoption of courtyard concept in traditional houses was to improve thermal comfort. Salem et al. (2010) stated that there is a link between privacy and thermal comfort by measuring the elements of courtyard housing form and how there adopt to the environment and climate. For instance, the separation of women and relationship of courtyard housing is assumed to reflect principally the thermal comfort needs of residents. Sharif et al. (2010) suggested that the strong relationship between social, physical and psychological dimension of housing regionalism could regulate an agreement between privacy and thermal comfort. This seems to emphasize the importance of courtyard for achieving both privacy and thermal comfort in houses.

Thermal comfort was achieved in traditional buildings through compact urban form, orientation, natural ventilation, shading and passive cooling (Ajaj and Pugnaloni, 2004). Khoukhi and Fezzioui (2012) stated that modern houses were designed and erected without traditional design techniques thereby ignoring cultural and climatic factors, which make indoor spaces in modern houses to be very hot. Hence, there is thermal discomfort in most contemporary buildings leading to too much dependence on heating and/or cooling equipment to improve thermal comfort in buildings. This equipment consumes energy; increase energy costs and have negative impact on the environments. In addition, Leylian et al. (2010) have evaluated the users' thermal satisfaction of 90 occupants (30 modern and 60 traditional buildings) by a questionnaire in hot arid climate in Kashan, Iran. The main outcome was the modern houses could not provide cooler indoor environment than traditional buildings. Hence, the majority user's perception of indoor temperature in summer in modern buildings was hot with 69% while in traditional buildings was cool with 64%. Figure **2-11** illustrates User's perception of indoor temperature in summer.

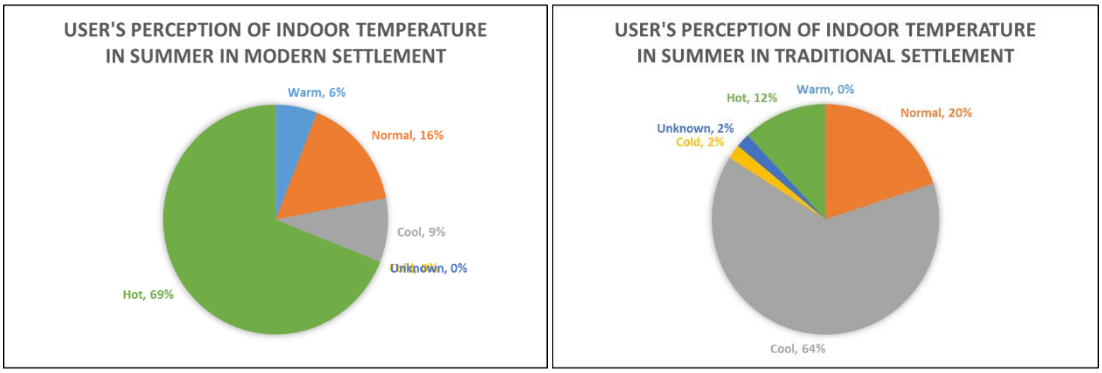


Figure 2-11 User's perception of indoor temperature in summer

Source: adapted from Leylian et al. (2010)

Almansuri (2010) stated that the structure and services of the modern urban built environment accounts for the most energy-consuming sector. Moreover, modern urban forms were implemented without proper study of their side effects. For instance, in Tripoli, most buildings require mechanical cooling systems to achieve thermal comfort. These has led to energy waste, ill health, pollution and other environmental problems. Designing buildings without considering local climate and culture can lead to loss of cultural identity and comfort challenges in buildings leading to high-energy demand.

Almansuri (2010) designed a model concept with sustainable housing criteria to meet people's needs. These criteria are:

- The user's socio-cultural values
- Climatic conditions
- Conservation of Energy
- Location (site conditions)
- Natural light and ventilation
- Efficiency of water
- Light colours
- decrease noise pollution
- Flexibility

The model can be adapted to different location and needs of users based on the creativity of the designer. The model showed how traditional architectural principles can be used in contemporary buildings to achieve the present needs for modern living in Libya. The researcher concluded by suggesting that future research should evaluate indoor thermal comfort and energy consumption in buildings using building energy performance modelling software for more quantifiable data.

Figure 2-**12** and

Figure 2-13 show the main design concepts of the Tripoli model and Table **2-1** shows compared the advantages of courtyard design and contemporary houses. As well, Leylian et al. (2010) suggested that in hot climate regions, the thermal performance of the building should be calculated during the design stage by evaluating a dynamic model of heat transfer, and the heat capacity of the building envelope.

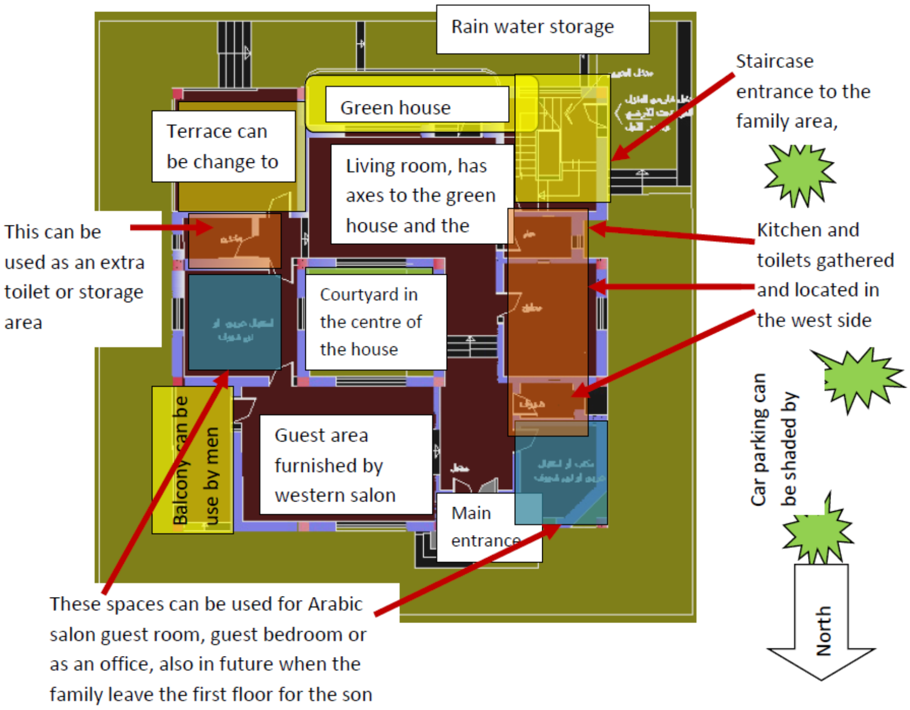


Figure 2-12 Ground floor explains the functions and gave design reasons

Source: Almansuri, (2010)

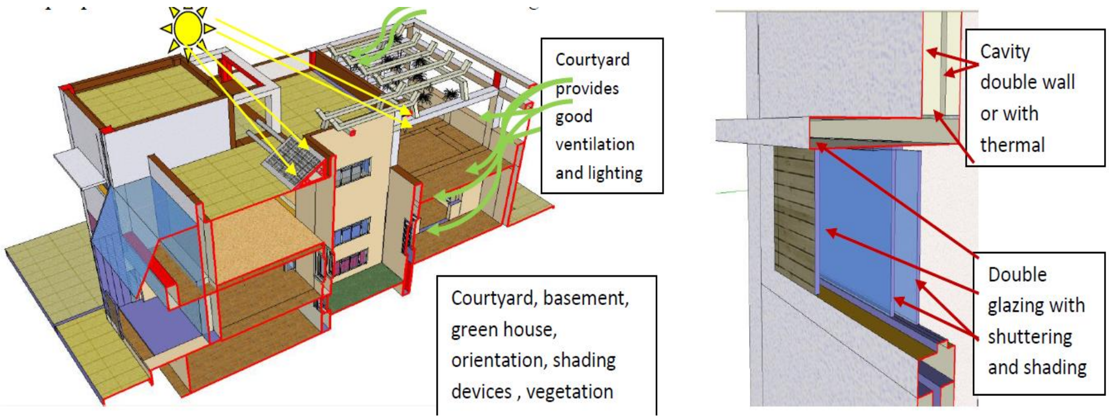


Figure 2-13 the relation between the courtyard and other functions, external wall and windows

Source: Almansuri, (2010)

Table 2-1 comparison between the advantages of traditional courtyard houses and contemporary houses

Advantages of traditional courtyard house and contemporary house	
Traditional courtyard house	**Contemporary house**
It provides privacy from streets, neighbours and visitors	It offers different spaces for varied functions
It is a space for family gathering, activities and meeting friends	It has high quality of finishing
It is a safe playing area for children and allows their mothers watch them easily	It has a good of arrangement of interior space
It is a quiet space, which protects a family against the street noise	It offers more privacy in terms of separation between brothers and sisters
It provides air movement ventilation	It is more structurally stable
It provides natural lighting and shading space	

Source: adapted from Almansuri, (2010)

2.6 Energy Efficient Buildings

Energy efficiency refers to the use of less energy to achieve the same service. Etiosa (2009) defined energy efficiency as using energy in a manner that minimise the amount of energy needed for building services. Where there is a benchmark on energy consumption per square meter of the floor of a building, UNIDO (2009) referred to energy efficiency in buildings as the degree to which the particular building measures up to the required energy consumption benchmark under defined climatic conditions. Energy efficiency can be referred to as the first significant step toward realizing sustainability in buildings. Energy efficient buildings on the other hand are those buildings that achieve the lowest possible energy consumption requirements with considerable use of energy resources employing energy efficiency techniques (Radhi, 2008).

A study by Meier et al. (2002) proposed three criteria for an energy efficient building. These are:

- The building must be furnished with energy efficient equipment and materials for the context and conditions.
- The amenities and services to be provided must match the requirements for the building.
- The building operation must show evidence of reduction in energy consumption compared to other similar buildings.

Energy efficient buildings have several advantages. Energy efficiency in buildings help to downsize increasing cost of energy, improve value and competitiveness of buildings and CO_2 emission (Meier et al., 2002). Ashen (2009) posited that energy efficient buildings help to reduce energy consumption by buildings and decrease environmental pollution.

Moore et al. (2013) identified two major approaches for achieving energy efficient buildings for the various climatic zones in the world. These are easy efficiency strategy and advanced efficiency strategy. The easy efficiency strategies deal with passive design techniques of achieving energy efficiency in buildings, which are low cost in comparison with the advanced efficiency method. Their study argued that the easy efficiency strategy could lower energy consumption in buildings between 40 – 60% compared to similar conventional buildings. On the other hand, the Advanced Energy Efficiency approach is divided into Ultra-Low Energy Buildings (ULEB), "Nearly Zero, and Plus-Energy Buildings" (nZEB/PEB). Ultra-Low Energy Buildings (ULEB) is an enhancement on Low Energy Buildings, which makes buildings to require approximately 90% less energy than conventional new buildings. Nearly Zero and Plus-Energy Buildings (nZEB/PEB) is a further development of ULEB. Nearly Zero and Plus-Energy Buildings deals with the adoption of on-site renewable energy technologies for generating power towards meeting both cooling and heating demands of buildings (Moore et al., 2013).

This research aims to achieve energy efficiency in buildings in Benghazi through the adoption of passive design techniques with a major focus on the building envelope and buildings' occupants' behaviour. Hence, the study focuses on the adoption of the easy efficiency strategy.

2.7 Thermal comfort

Researchers have offered several definitions of the concept of thermal comfort. Fanger (1970) defines thermal comfort based on physiological strain factors, as “the sensation experienced by a person was a function of the physiological strain imposed on him by the environment”. The American Society of Heating and Refrigerating and Air-conditioning Engineers defined thermal comfort as “that condition of mind which expresses satisfaction with the thermal environment” (ISO 7730, 2005; ASHRAE Standard 55, 2010). This is the most widely recognized definition of thermal comfort. Nevertheless, other researchers have also defined thermal comfort base on their understanding of the concept. A study of Markus and Morris (1980) defined thermal comfort as “that state in which a person will judge the environment to be neither too cold nor too warm – a kind of neutral point defined by the absence of any feeling of discomfort”. Hensen (1991) defined thermal comfort as a state where there is no driving impulse to modify the environment through behavioural change. Humphreys (1995) defined thermal comfort as “a condition of satisfaction expressed by occupants within a building to their thermal environment”. To achieve a common ground for all the definitions of thermal comfort, Parsons (2002) argued that a range of environmental and personal factors where people feel comfortable must be taken into account. In line with this, Nicol (2008) argued that since comfort is a psychological state defined by climate, culture, and economics, it is difficult to define a temperature at which everyone will feel comfortable. This seems to mean that the definition of thermal comfort focuses on a condition where the highest possible percentage of a population feel comfortable based physiological, psychological and physical factors.

There are indicators of thermal comfort. Macpherson (1962) identified six indicators of thermal comfort that affects thermal sensation. Four of these indicators are environmental or physical variables while the other two factors are personal variables. The environmental factors are relative humidity, air temperature, air velocity, and radiant temperature while personal factors are activity level (metabolic rate) and clothing insulation.

2.7.1 Predictive Mean Vote (PMV) and adaptive method

Predictive Mean Vote (PMV) and Adaptive method are two popular models developed to predict thermal comfort. Fanger (1970) developed PMV and Predicted Percentage of Dissatisfaction (PPD) as comfort indices to predict thermal comfort standards for air-conditioned buildings. This model has been adopted in different countries of the world to define thermal comfort in air-conditioned buildings (Chandel and Sarkar, 2015). Research has shown that too much dependence on PMV models does not give room for relevant contextual, social and cultural factors in the prediction of thermal comfort (Lutzenhiser, 1992). This argument later led to the production of an alternative comfort model, the adaptive method, which involves field measurement focusing on perceptual and contextual indices. These methods are discussed in the next subsections.

2.7.1.1 Predictive Mean Vote (PMV)

PMV is used to describe thermal sensation votes on a seven-point scale (cold -3, cool -2, slightly cool -1, neutral 0, slightly warm 1, warm 2 and hot 3). On this PMV sensation scale, ASHRAE recommended acceptable PMV range between -0.5 to +0.5 for thermal comfort in interior spaces. Zero PMV on the seven-point scale provides optimum thermal comfort conditions. Positive PMV value on the scale means the temperature is above the optimal value while a negative number means the temperature is lower than the optimum comfort condition (Yau and Chew, 2014). Predicted Percentage of Dissatisfaction (PPD) indicates the percentage of the number of people susceptible to feeling too cold or too warm in a given thermal environment. PPD is used to predict the percentage of building users that are expected to be dissatisfied with the indoor thermal conditions. PPD relied on PMV in the sense that as PMV proceeds from neutral, PPD increases. ASHRAE recommended 10%-person dissatisfaction as the acceptable PPD range for thermal comfort in buildings. At PMV of -0.5 and +0.5, the PPD curve corresponds with 10% dissatisfaction. Figure 2-14 shows the relationship between PMV and PPD.

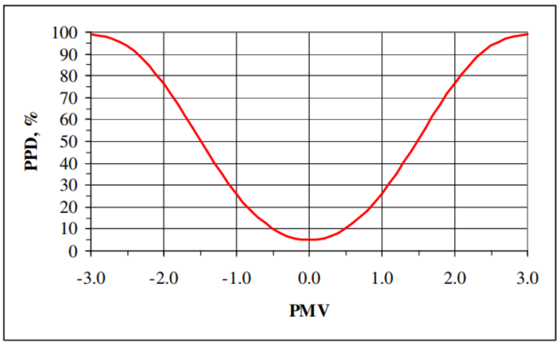


Figure 2-14 predicted percentage dissatisfied (PPD) as a function of the predicted mean vote (PMV)

Source: ASHRAE Standard 55, 2010

2.7.1.2 Adaptive Method

The concept of adaptive approach is based on the idea that past thermal history and contextual variables modify building occupants’ thermal preferences and expectations (ASHRAE, 2009). The adaptive comfort method relied on the principle that when there is thermal discomfort in buildings, building users react in various ways to achieve comfort. It works on the principle that links outdoor temperature with building occupants and their control on their immediate thermal environment enabling them to adopt to a broad range of comfort conditions (Nicol and Humphreys, 2002). The response to achieve comfort involve changing the level of clothing, activity or location ((Lutzenhiser, 1992); Nicol and Humphreys, 2002). The adaption actions can be physiological, behavioural or personal environmental controls (Nicol, 1993). Adaptive comfort model has been regarded as “the most suitable for free-running naturally ventilated buildings where mechanical cooling and heating are not present and occupants have total control on operable windows” (Chandel and Sarkar, 2015, p.876).

2.7.2 Determination of comfort zones using PMV or adaptive method

There are two methods of determining thermal comfort zones namely PMV method and adaptive method. Using the PMV method involves air temperature, mean radiant temperature (MRT), air speed, humidity, metabolic rate, and clothing level. The value gotten from the parameters involved in the calculation of comfort zone through the

PMV method will determine the comfort zone for the particular microclimate on the psychometric chart. Figure **2-15** shows a typical psychometric chart indicating the comfort zone in purple colour.

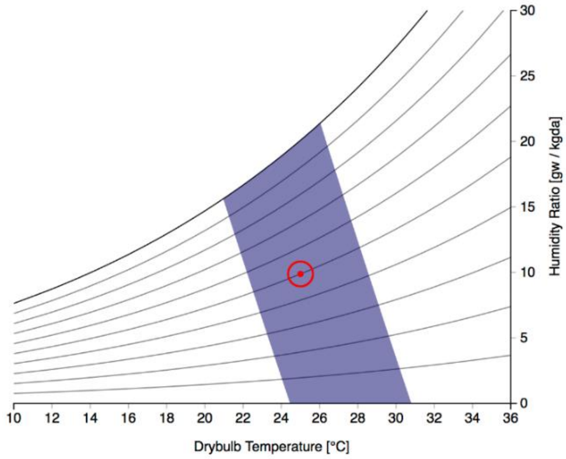


Figure 2-15 a typical psychometric c

Source: ASHRAE Standard 55, 2010

Adaptive method, on the other hand, involves the measurement of air temperature, calculation of MRT and the prevailing mean outdoor temperature. Operative temperature is determined by calculating the average MRT and dry bulb temperature. Hence, on the adaptive comfort chart, the comfort zone is determined by operative temperature and prevailing mean monthly outdoor temperature. Figure **2-16** shows a typical adaptive chart. The detail processes for the determination of comfort zones using the PMV method and adaptive method for this study can be found in chapter 5 under section 5.4.4.

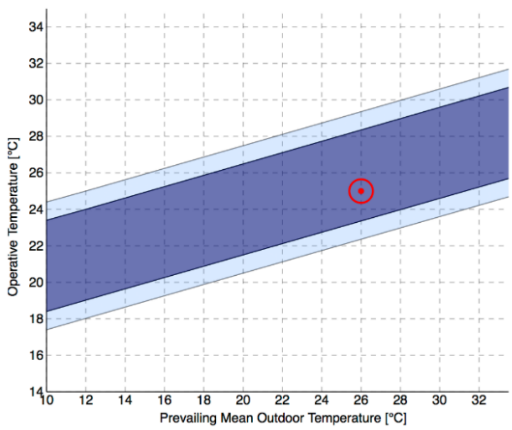


Figure 2-16 a typical adaptive chart

Source: ASHRAE Standard 55, 2010

2.8 Factors that affect energy consumption in buildings

Several factors determine the level of energy consumption in buildings. These factors include the climatic zone, building form, building orientation, building envelope, buildings occupants' behaviour and the type of ventilation systems. Among these factors, the climate of a location, the materials that constitute the building envelope and buildings occupants' behaviour play significant roles in terms of energy demand in buildings. The section presents a discussion on climate, building form, building orientation, building materials, building envelope, buildings occupants' behaviour, lighting systems and appliances, ventilation systems and building design.

2.8.1 Climate

Koenigsberger et al. (1974) define climate as the integration in time regarding the average weather conditions that characterize a particular geographical location for a period, typically for about 30 years. Climate is the weather condition for a long period; it is the sum of the statistical weather data, which describes a particular location, place or region (Clear, 2016). The climate of a place can be described used some variables which include temperature, humidity, rainfall, wind, cloud cover, and sunshine. Previous researchers have classified climates into different groups. Koppen classification of climates involves quantitative definitions for the climate categories based on temperature and precipitation indices (Briggs et al., 2003). Koppen classified the various climates into five major groups, types and subtypes. These are tropical, dry (arid and semi-arid), temperate, continental and polar climates (Koppen, 1918). A study of Mathur and Chand (2002) revealed five major climatic zones of hot dry, warm-humid, cold, temperate and composite climates. Their study identified the mean monthly maximum temperature and relative humidity of the various classifications. Table **2-2** shows the classifications.

Table 2-2 Five climatic zones

Climatic zone	Mean monthly maximum temperature ^{0}C	Mean monthly relative humidity %
Hot-dry	Above 30	Below 55
Warm-humid	Above 25	Above 75
Temperate	Between 25-30	Below 75
Cold	Below 25	All vales
Composite	-	-

Source: Mathur and Chand, 2002

Hui (1997) grouped climates into four classifications for design purposes based on thermal situation in a particular climatic region. These are cold climates, temperate climates, hot dry (arid) climates and warm humid climates.

The various climatic zones in the world have their design requirements irrespective of how they have been classified by researchers. Energy demand for heating or cooling or both depends on the particular zone. In addition to factors like building materials, energy efficiency technologies and expertise, energy price and building policies, the climate has been referred to as the most significant factor determining the right approach to achieving energy efficiency in buildings (Moore et al., 2013). Hence, it is important and necessary for every climatic zona in the world to identify and apply suitable approaches for reducing energy demand in buildings.

In Mediterranean climate like Benghazi, heat gain is a major challenge to the design of buildings. To reduce the high heat gain in such climate, Hyde (2002) suggested that building design should minimise west wall, have the moderate surface area, especially on the south wall and have small to moderate size of windows. Table **2-3** shows different approaches to the design of building form based on the climatic zone.

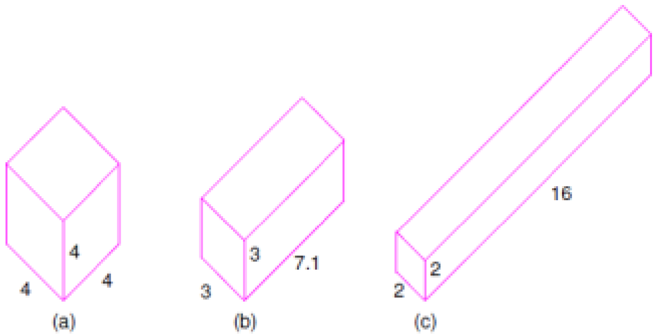
Table 2-3 the preferred requirements for building form in different climate zones

Climate	Element and requirement	Purpose
Warm humid	Minimize building depth	For ventilation
	Minimize west facing wall	To reduce heat gain
	Maximise south and north walls	To reduce heat gain
	Maximise surface area	For night cooling
	Maximise windows wall	For ventilation
Composite	Controlled building depth	For thermal capacity
	Minimize west wall	To reduce heat gain
	Limited south wall	To increase thermal capacity
	Medium area of windows wall	For controlled ventilation
Hot dry	Minimize south and west walls	To reduce heat gain
	Minimize surface area	To reduce heat gain and loss
	Maximise building depth	To increase thermal capacity
	Minimize windows wall	To control ventilation, heat gain and light
Mediterranean	Minimize west wall	To reduce heat gain (summer)
	Moderate area of south wall	To allow (winter) heat gain
	Moderate surface area	To control heat gain
	Small to moderate windows	To reduce heat gain but allow winter light
Cool temperate	Minimize surface area	To reduce heat gain
	Moderate area of north and west walls	To receive heat gain
	Minimize roof area	To reduce heat loss
	Large windows wall	For heat gain and light
Equatorial upland	Maximise north and south walls	To reduce heat gain
	Minimize west -facing walls	To reduce heat gain
	Medium building depth	To increase thermal capacity
	Minimize surface area	To reduce heat loss and gain

Source: Hyde (2012)

2.8.2 Building form

Building form can be used to enhance heat gain or loss depending on the design intention. Where the design requirement is to improve heat gain, the focus should be on maximizing the solar radiation and vice versa when the need is to reduce heat gain (Joelsson and Fröling, 2012). Building shape is a relevant design element that can have a significant impact on energy demand and consumption (Szuppinger, 2011). To reduce energy consumption in buildings, proper consideration should be given to surface to volume ratio (Behsh, 2002). The lower the surface area to volume ratio, the better the performance of the building in terms of energy efficiency. The high surface area to volume ratio means high heat gains (Nayak and Prajapati, 2006). Figure **2-17** shows a comparison between different shapes of buildings indicating their surface area to volume ratio.



SOLID SHAPE	SURFACE AREA 'S'	VOLUME 'V'	SURFACE AREA/ VOLUME RATIO 'S/V'
a	96	64	1.5
b	103.2	64	1.61
c	136	64	2.13

Figure 2-17 Surface area to volume ratio (S/V ratio) for a few building shapes

Source: Nayak and Prajapati, (2006)

In figure 2-17 building shape (a) has the surface area to volume ratio of 1.5. Hence, this building is expected to have lower heat gain and heat loss compared to (b) and (c) having 1.61 and 2.13 surface area to volume ratio respectively. Grisso et al. (2009) maintained that well-designed buildings with a simple shape and compact form are more energy efficient compared with irregular shape buildings. Another study by Mikler et al. (2008) compared different shapes of buildings in terms of their surface area to volume ratio. Their study seems to confirm that the high surface area to volume ratio means poor performance in terms of energy efficiency. Figure **2-18** compares five different shapes of buildings having a different surface area to volume ratio on the scale of best to worst.

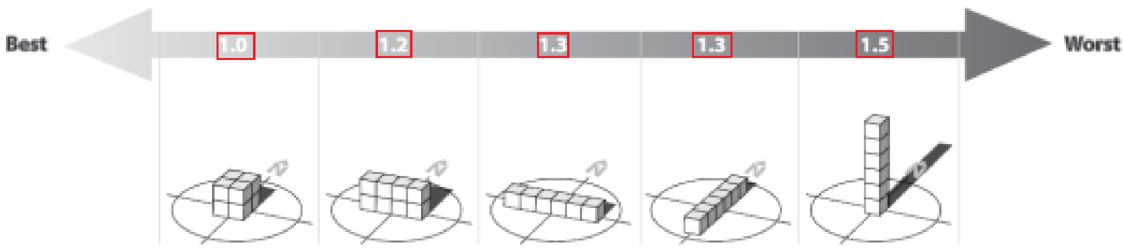


Figure 2-18 the effect of the envelope to volume ratio on energy efficiency

Source: Mikler et al. (2008)

The total surface area of the building that is exposed to solar radiation determines both heat gain and heat loss in buildings, which places the significant demand of cooling systems. The building form determines the area of exposed surfaces, which go a long way to affect the thermal performance of building (Pacheco et al., 2012). In addition to building shape, Bektas and Aksoy (2011) identified some physical-environmental and design parameters that can influence energy consumption in buildings. Table **2-4** shows these parameters which point to the multiplicity and complexity of the several design variables that affect building energy performance.

Table 2-4 building energy requirements

Physical-environmental parameters	Design parameters
• **Daily outside temperature (^{0}C)** • **Solar radiation (W/m^2)** • **Wind direction and speed (m/s)**	• **Shape factor** • **Transparent surface** • **Orientation** • **Thermal-physical properties of building materials** • **Distance between building**

Source: Bektas and Aksoy, (2011)

Previous researchers also agree that energy demand through the building envelope depended on the coefficient of building shape (Oral and Yilmaz, 2002; Oral and Yilmaz, 2003). Other studies are of the view that the building shape factor relies on the solar heat factor and the ratio of external glazing (Ourghi et al., 2007; AlAnzi et al., 2009).

Another significant aspect of building form or shape involves the provision of courtyards. Previous researchers have dwelled on courtyard design and its effect on thermal comfort in different climatic zones (Ratti et al., 2003; Yasa and Ok, 2014). The shading effect provided by the courtyard during summer when there is high demand for cooling is minimal due to high temperatures. Hence, the study of Yasa and Ok (2014) concluded that the benefits of courtyard design are hot arid and hot humid climates is minimal. Nevertheless, Bhavan, (2013) maintained that courtyards are important for improving ventilation and have cultural benefits. They added that to enhance the performance of courtyards, there should incorporate cooling elements like trees, soft paving and water bodies. Moreover, the ratio of width to height of the courtyards should be close to 1:1 for proper shading. Figure 2-19 shows a typical modern courtyard height to width ratio of 1:4 with no adequate shading and possible strategies for a courtyard with adequate shading of height to width ratio close to 1:1.

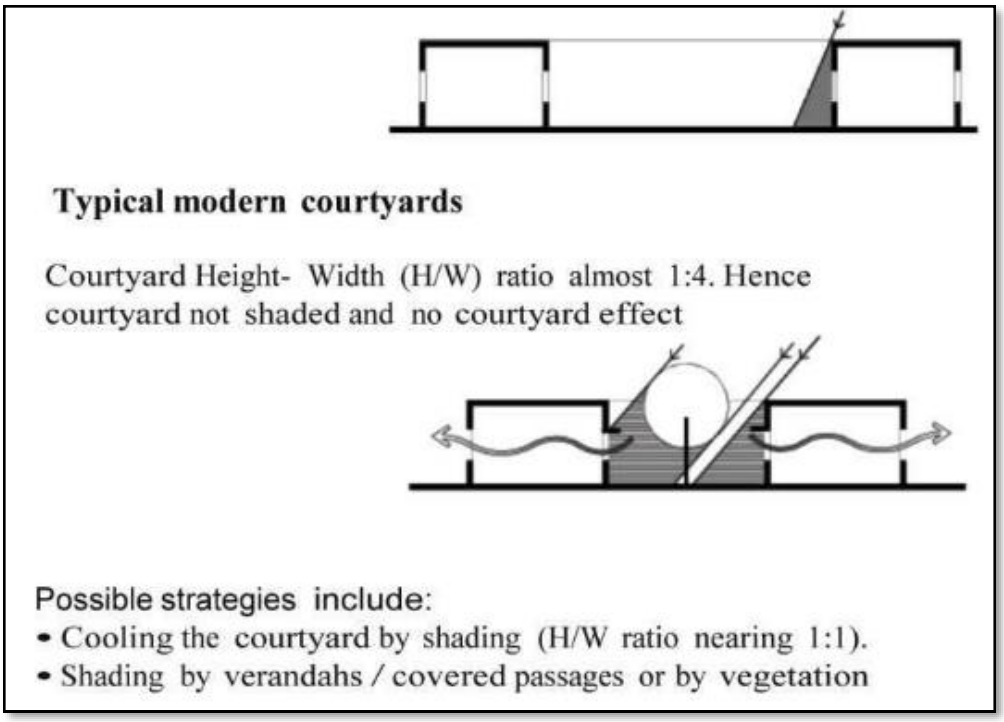


Figure 2-19 a typical modern courtyard

Source: Bhavan, (2013)

2.8.3 Building orientation

Orientation is an important design factor especially when design aims to take advantage of the effect of solar radiation and prevailing wind. Sartogo (2008) who supported this view argued that proper orientation of buildings would improve natural ventilation and provide appropriate control of solar gain. It is important to site buildings in a manner that does not restrict airflow but captures cool breezes to improve thermal comfort. Evans (2007) contended that building orientation, proper placement of buildings and the arrangement of external spaces could enhance the admission of cool breezes into buildings. The major aim of building orientation in hot climates is to reduce the impact of insolation and enhance ventilation in buildings (Givoni, 1998). Heine (2010) revealed some relevant information on the effect of solar radiation on building surfaces. These are:

- The effect of solar radiation is greatest on horizontal building surfaces.
- East and west facades of buildings are mostly affected by solar radiation especially in the morning and in the evening than north and south vertical elevations.
- Southeastern elevations receive the lowest solar radiation during the summer and high solar radiation during winter or cold season.

To determine the best orientation for buildings, it is important to understand the sun paths and its effect on building facades. Moreover, relevant information on the solar altitude and azimuth could help designers to choose building elements such as size, orientation, fenestration, shading devices and building materials (Clear, 2016). To minimise the adverse effect of solar radiation in summer and capture it in winter, the shorter of the building should face east or west Elaiab (2014). Figure **2-20** shows the best orientation for buildings in Libya. To avoid heat gain in buildings, particularly in summer, Bahrami (2008) maintained that adequate shading devices should be provided on glazed external surfaces.

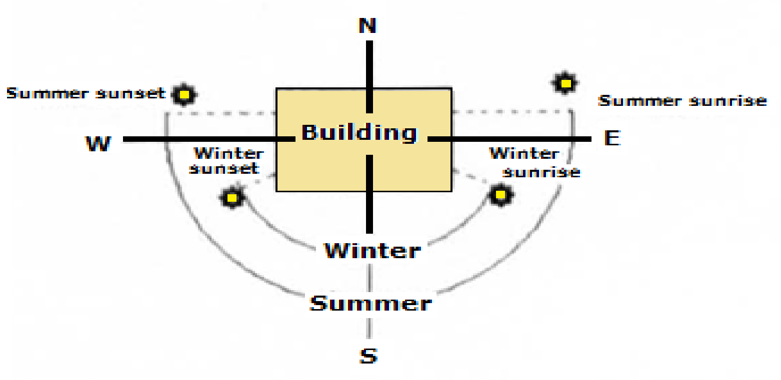


Figure 2-20 the best orientation for buildings in Libya building orientation in Libya according to sun-paths

Source: Elaiab, (2014)

2.8.4 Building materials

Building material specification is key to reducing heat gain or loss in buildings. Hyde (2002) corroborated this by stating that building material selection plays an important role regarding thermal comfort and energy consumption in buildings. Therefore, to achieve energy efficiency in buildings, it is important to select appropriate building materials for the building envelope.

Building materials for construction purposes are generally classified into two major categories namely high thermal mass materials and low thermal mass materials. Thermal mass refers to the ability of materials to absorb heat or cold, store it and dissipate it later (Wheatley, 2008). Heat storage relates to the density of the material and the specific heat and the product of these is termed the thermal capacity also kwon as thermal mass. The ability of building materials to store heat help to achieve thermal comfort by providing a time delay for the flow of heat or cold. Building materials with high thermal mass include concrete, bricks, and stone. High thermal mass materials absorb heat at a lower rate making them highly effective in reducing heat transfer (Mirrahimi et al., 2016). On the other hand, materials with low thermal mass include steel and aluminum. These materials are good conductors of heat. Hence, they absorb heat at a faster rate and cool down quickly as well.

Research has shown that building construction materials with high thermal mass are the most suitable for hot dry climate (Arup, 2016). High thermal mass is most appropriate for climatic zones where diurnal temperature variation is more than 10^0C (Arup, 2016).

The energy performance of building materials depends on their thermo-physical properties. These properties include conductivity, specific heat capacity, resistance and surface convective coefficients (Iyengar, 2015). Manioglu and Yilmaz (2008) corroborated this by positing that the thermophysical properties of building materials are very relevant owing to the influence on building indoor thermal conditions. Hence, appropriate building material specification considering their level of heat transfer can lead to energy reduction in buildings.

Insulation of building materials is also a key factor for achieving energy efficiency in buildings. Sadineni et al. (2011) referred to insulation as a single or combination of materials that can help in the reduction of heat flow due to its high thermal resistance.

Thermal insulation is significant at reducing space-conditioning loads, which can lead to savings on energy cost in buildings (Al-Homoud, 2005). The location on the insulation is very important in achieving its relevance. Studies have shown that the insulation should be placed on the external side of the building envelope (Bansal et al., 1994; Arup, 2016). Among the insulation materials investigated, polystyrene material is found to be the most economical and more energy saving type with an optimum thickness of 9.3 cm (Al-Sanea and Zedan, 2002). In Mediterranean climates like northern Algeria, the use of passive cooling techniques could rise the thermal resistance of the building envelope by insulation materials which can significantly provide potential for energy savings, Imessad et al. (2014) found by adding 9cm polystyrene in exterior walls, cooling energy demands are decreased by approximately 35% compared to non-insulated building. In addition, to improve the design of energy-efficient of single-family villa in Tunisia, it is found that by applying polystyrene 6 cm in exterior wall and roof can save up to 59% compared to the current construction practices of homes (Ihm and Krarti, 2012).

Another relevant aspect of building material in terms of the thermal performance of the building envelope is the U-value. In building materials, heat flow is measured by conductance and for layered assemblies; conductance is combined into a single termed U-factor or U-value. U-value refers to the heat transfer potential of materials. A material with high U-value is a good conductor while a material with low U-value is a good insulator. R-Value, on the other hand, refers to the ability of materials to resist the transfer of heat a certain thickness. When there is there is a need for proper insulation in buildings, materials with high R-Value are preferable. U-Value is the mathematical reciprocal of R-Value; that is U-Value = 1/R-Value and R-Value = 1/U-Value. Table - shows the U-value and R-value of a variety of roof and wall materials with or without insulation.

Table 2-5 a variety of roof and wall materials with or without insulation and their associated U and R-Values.

Table 8: R and U values provided by DesignBuilder software		
Construction	**Typical R value (m^2K/W)**	**Typical U value (W/m^2K)**
Metal roof, void, ceiling	0.51	1.95
Metal roof, void, 100mm mineral wool, ceiling	3.22	0.31
Concrete roof with no insulation	0.77	1.30
Concrete roof with 50mm polystyrene on top	2.69	0.37
150mm hollow sandcrete block wall (rendered)	0.53	1.9
230mm hollow sandcrete block wall (rendered)	0.65	1.6
150mm hollow sandcrete, 25mm polystyrene, 25mm cavity, 100mm brick wall	1.28	0.8
150mm stabilised soil block with internal render (class A)	0.33	3.06 [13]

Source: Arup, (2016)

2.8.5 Building envelope

The building envelope refers to the external shell of a building which consists of various building elements like floor, walls, windows, shading devices and roof (Sadineni et al., 2011). It separates the building interior from the exterior climatic conditions and accounts for the largest share of the transfer of heat or cold into the building. Previous research has argued that the building envelope has the highest influence on building occupants' comfort, especially in naturally ventilated buildings (Pereira and Ghisi, 2011; Hwang and Shu, 2011). The building envelope provides protection from weather and climatic elements for the building occupants. Therefore, a good design and appropriate specification of the elements that make the building envelope can help to reduce energy demand as well as improve indoor temperature in buildings (Kim et al., 2007; Aldossary, 2015). A study by Sadineni et al. (2011) revealed that building envelope optimization could lead to a saving of nearly 47% during peak cooling demands and up to 35% saving in total energy use. Their study also showed that by adding insulation to the building envelope components, an energy saving of 20-40% was realized and a reduction of 30% of space cooling loads using external shading devices and light colour walls and roof. This section focuses on various components of the building envelope and their influence on thermal comfort in buildings. These are floor, walls, windows, and roof.

2.8.6 Floor

The floor is an important aspect of the building envelope. The ground floor is key to energy efficient design depending on the climate due to its closeness or contact with earth, which is always cool. The building materials usually used for the construction of ground floor include concrete, steel, and timber. Important factors about floor construction relate to the level of heat gain or loss and time factor (Iyengar, 2015).

Concrete has high thermal mass and the ability to improve cooling in buildings, especially when it is shaded from the effect of solar radiation. On-ground, uninsulated concrete floor slab has a surface temperature that is nearly the same as the earth temperature. Its contact with the earth makes it absorb heat during the day and release it at a later time to improve thermal comfort in buildings. The importance of buildings contacts with the ground to improve indoor comfort has been documented in the existing literature (Chojnacki, 2003; Khanghahi and Abdolmaleki, 2011; Geetha and Velraj, 2012). This might be the reason why the on-ground concrete floor slab is extensively used in Benghazi.

2.8.7 Walls

Walls form a major part of the building envelope that receive a significant amount of solar radiation. The ability of walls, particularly external walls to store and release heat is key to achieving thermal comfort conditions and reducing energy consumption in buildings. Previous research revealed that doubling the thickness of the external walls on the east and west sides of the building, use of hollow clay tiles, and suitable horizontal overhangs of the four facades can reduce cooling load by 64% and reduce the total energy demand of buildings by 26% (Ahsan and Svane, 2010). To downside energy consumption in buildings, material specifications should focus on reducing heating or cooling demand (Almansuri, 2010).

Baccoush (2006) suggested three types of wall design to minimise heat gain in hot climates. Figure **2-21** shows the three types of wall.

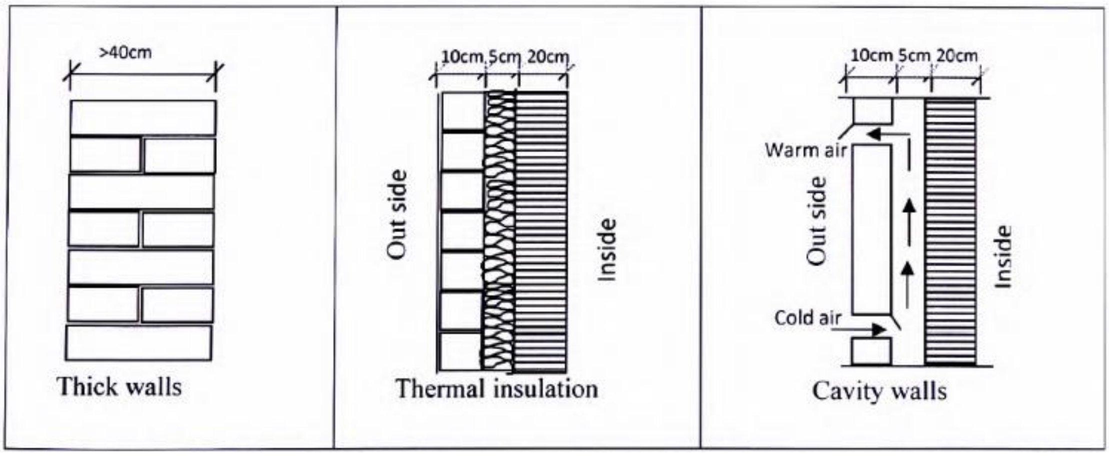


Figure 2-21 the three types of walls

Source: Baccoush, (2006)

The first type of wall involves using thick walls having more than 40cm. The second type is an insulated wall comprising of three layers having a total thickness of 35cm while the third type is a cavity wall of the same thickness but with air cavity instead of an insulation.

Previous research suggested doubling the external walls, use of insulation and cavity walls for achieving energy efficiency in buildings (Utama and Gheewala, 2009, Radhi, 2008; Najim, 2014). This seems to confirm the suggestion of Baccoush (2006), who suggested thick wall, insulated walls and cavity walls as means of reducing heat gains in hot dry climates.

Utama and Gheewala (2009) studied the energy performance of both single and double walls for buildings in Jakarta, Indonesia. They tested clay bricks with a different configuration for double and single walls separately. Their study revealed that double wall performed better with savings of 40%. Fang and Li (2000) suggested 37cm thickness for a brick wall, 40 to 45cm for high concrete walls and 35-40cm for low concrete walls for passive solar-heated residential buildings. Although it is expensive to build a thick wall, Sisman et al. (2007) are of the view that its operating cost will lead several benefits, particularly in terms of economic and environmental benefits.

As discussed earlier, wall insulation is relevant to achieving thermal comfort in buildings, especially in hot dry climates. Suitable application of thermal insulation on the building envelope has been regarded as the effective means of reducing the transfer of heat and energy demand by buildings (Najim, 2014). Heier et al. (2015) state that proper insulation can significantly reduce annual cooling demand and peak cooling load for buildings in both hot dry and hot humid climates. A study by Radhi (2008) revealed 25% savings in energy consumption due to the use of thermal insulation on the external walls of buildings in Bahrain. The thickness of the insulation material is relevant to its performance in terms of heat transfer. Xu et al. (2015) corroborated this when they stated that the thickness of insulation material is an important aspect of building design. Building codes and regulations in a different part of the world recommended between 25-30mm thick insulation for a 500mm thick wall (Sadineni et al., 2011). Balatturk (2006) revealed that insulation thickness of between of 20mm to 170mm could lead to energy savings of 22% to 79%.

The use of cavity walls on the external walls of buildings plays important roles in heat transmission, particularly in terms of energy consumption due to cooling (Najim, 2014). Cavity walls consist of outer and inner brick or block separated by an air gap referred to as cavity. In a typical cavity wall, the air gap hinders heat transmission into or out of buildings due to the property of air as a bad conductor of heat (Heier et al., (2015). Baccoush (2006) suggested 5cm air gap for a cavity wall.

ECBC (2007) suggested four ways of improving the thermal performance of walls. These are:

1. Increase the thickness of walls
2. Provide air cavity between the outer and inner leafs of walls
3. Apply insulation to the external surface of walls
4. Use light colour paint on the external surface of walls

2.8.8 Windows

Windows are a significant aspect of the building envelope that can have marked effect on energy consumption in buildings (Ralegaonkar and Gupta, 2010). In addition to the provision of physical and visual connection to the outdoor, windows allow heat and light into buildings and improve the aesthetics of the external facades of buildings. Windows provide both thermal and visual comfort in buildings. Appropriate design and specification of windows in terms of type, size, location, and shading are significant parts of the bioclimatic design (ECBC, 2007). This section presents a discussion on window glazing types, window-to-wall-ratio, and window shading.

a. Window glazing types

Until recently, single pane, clear glass was the main glazing material used for window construction. Different window glazing types have now emerged due to advance in technology and are used extensively for building construction. The most commonly used type of glazing according to previous studies are clear glass, heat absorbing glass, heat reflecting glass, low-emissivity glass, super-insulating glass and grey/ coloured glass (Givoni, 1998; Al- Tamini et al., 2011).

Different types of window glazing, whether clear, tinted or reflective have their solar heat gain coefficient (SHGC). SHGC is the ratio of the heat gain that is transferred through the glazing area to the incident radiation. Solar heat gain involves both the directly transmitted solar heat and absorbed radiation which is transferred through radiation, conduction or convection into interior spaces. The heat transfer through the glass pane is dimensionless and ranges from 0 to 1. Glass with low SHGC can have a significant effect in reducing cooling demand in hot climates (ECBC, 2007). Elaiab (2014) stated that tinted or reflective glass could be used to solar gain thereby reducing energy demand in buildings.

Glazing types have been classified differently to include single, double and triple glazing. A different construction of glazing types has a different solar gain factor. Figure **2-22** shows examples of glazing types with their corresponding solar gain factor (S_c).

Glazing type	Solar gain factor, S_c
Single clear glass	0.76
Single clear glass with blind	0.34
Double glazed, clear glass	0.62
Double glazed with low-e inner pane	0.62
Double glazed with blind	0.29
Triple glazed, clear glass	0.52
Triple glazed with low-e mid pane	0.53

Figure 2-22 example average solar gain factors for different glazing types

Source: adapted from CIBSE Guide A, (2006)

b. window-to-wall-ratio

Window-to-wall-ratio (WWR) is ration the total vertical fenestration area to the total exterior wall area of a building. The total area of the exterior wall is measured horizontally from the exterior surface and vertically from the top of the floor to the bottom of the roof. Figure **2-23** the WWR of the wall = (a x b)/ (H x W).

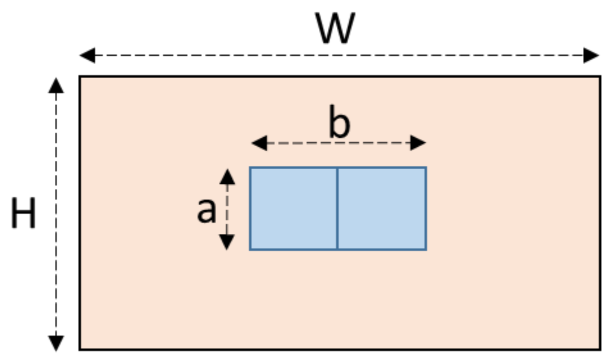


Figure 2-23 calculation of WWR

Source: ECBC (2007)

WWR is relevant to the transfer of solar radiation into interior spaces in buildings (Ralegaonkar and Gupta, 2010). A research conducted by Liping and Hien (2007) revealed that thermal comfort and ventilation is buildings can be improved by about 13% with an increase in WWR of between 12 – 24%. Nevertheless, a further increase in WWR can significantly increase heat gain and energy demand in buildings (Liping and Hien, 2007; Eskin and Turkmen, 2008).

Mandilawi (2012) stated that WWR for hot arid climates should not exceed 15% in order to prevent overheating and thermal discomfort in buildings. Liping and Hien (2007) recommended 24% WWR for the hot humid climate of Singapore. Oral et al. (2004)

suggested 20% or high WWR for thermal and visual comfort in buildings. CIBSE (1998) recommended 30% WWR to minimise energy consumption in buildings. These studies emphasize the relevance of WWR concerning thermal comfort and energy consumption in buildings.

c. window shading

Shading devices contribute to the reduction of solar gains in buildings. It is a very important design element, particularly in hot climates, where there is enormous cooling demand. Shade screens that are low cost and flexible help to absorb and reflect a significant portion of solar radiation before reaching external windows (Lstiburek, 2004). Suitable blinds, overhangs, and awnings can reduce cooling energy in summer. Kim et al. (2017) posited that using exterior shading devices on windows on the western façade of buildings could help to maximize the benefits of internal shading devices. To prevent buildings from overheating in summer months, proper shading devices should be provided to prevent the effect of direct sunlight. This was the view of Elaiab (2014) who argued that external window blinds are more effective compared with internal blinds as they significantly reduce the amount of solar radiation entering buildings.

The importance of shading devices on cooling demand and thermal comfort in buildings have been properly studied (Wang et al., 2007; Wong, 2008; Al-Tamini, 2011; Ralegaonkar and Gupta, 2010). A study on the effect window shading devices on cooling energy demand in Singapore by Wang et al. (2007) showed approximately 3% savings by using 30cm deep horizontal shading device on external windows. Increase in the depth of the shading device to 60cm and 90cm led to savings of nearly 7% and 10% respectively.

2.8.9 Roofs

The roof of buildings receives a significant amount of solar radiation and plays significant roles in terms of energy consumption and thermal comfort. Ahsan and Svane (2010) stated that the roof is an important building element when it comes to energy conservation because of its exposure to solar radiation. They added it is the major cause of thermal discomfort in naturally ventilated buildings. Sailor et al. (2012) posited that appropriate energy efficient roof design could save up to 48% of energy consumption while vegetative roofs can cool demand up to 67%. To reduce energy consumption through roof design, roof insulation and colour of the roof are very important.

A well-insulated roof is an effective means of reducing solar gains through the roof structure of buildings. The insulation material, which should be placed on the external side of the roof, should be properly protected by waterproofing (ECBC, 2007). The thickness of the insulation material is key to its performance. Halwatura and Jayasinghe (2008) studied the effect of insulation on energy performance of buildings using 25mm and 38mm thick insulation materials. The study showed that the insulation material with a thickness of 38mm performed better. Therefore, it is important for designers to be aware of the performance of different sizes of insulation materials for proper specification. Halwatura and Jayasinghe (2008) stated that a properly insulated could perform better than lightweight roofs in hot and arid climates. This shows that insulation is important for improving thermal comfort and reducing energy demand by buildings in hot and dry climates.

Apart from roof insulation, a cool roof is another strategy employed for reducing heat gain in hot climates. Cool roofs are designed to reflect a significant amount of sunlight in order to improve indoor thermal comfort and reduce energy demand. Cool roofs are those roofs that can retain lower surface temperatures than conventional roofs (Urban and Roth, 2010). Suehrcke et al. (2008) in their study in hot climates classified roof colours into dark, medium, light and reflective colours. They stated that a significant reduction in heat flow could be achieved by using reflective or light colour roofs. Their simulation results showed nearly 30% reduction in heat gain compared to dark colour roofs. According to Urban and Roth (2010), the dark roof can absorb up to 90% of solar radiation and reflect about 5% to 20% of sunlight whereas light colour roofs have the ability to reflect 55% to 90% and absorb less than 50% of solar radiation. Hence, roof with high reflectance and emittance are suggested for buildings in hot dry climates due to high solar radiation.

2.8.10 Buildings occupants' behaviour

Building occupants' behaviour can have a direct or indirect effect on energy consumption in buildings. Hong and Lin (2013) stated that occupants' behaviour is among the most significant sources of uncertainty in the prediction of building energy performance using dynamic thermal simulation due to complexity and uncertainty in buildings' occupants' behaviour. Previous studies have shown that building occupants' behaviour can have a similar effect with mechanical cooling systems and appliances in terms of energy use (Haas et al., 1998; Van der Linden., 2006). Mahdavi et al. (2008) stated that good energy efficient building design and operational practice could lower energy use in buildings.

Despite the importance of building energy simulation tools, there are limited in determining the actual behaviour of buildings occupant, especially when there a lack of relevant data on the use of buildings by the occupants (Pan et al., 2017). Assumed occupants' behaviour could lead to error or lack of lack of confidence in the prediction of building energy demand with simulation tools (Wei et al., 2014). For more reliable simulation results, it is important to have relevant data on the way the building occupants make use of the building and applied this to energy modelling (Pan et al., 2017).

The areas that occupants' behaviour have an effect on buildings' energy consumption include opening and closing of windows, turning on/off of electrical equipment, cooling, and heating systems and control of heating and cooling set points. A study by Hong and Lin (2013) revealed that modification of building occupants' behaviour could lead to savings of 5% to 30% of energy demand in buildings. A study by Saelens et al. (2011) on the effect of occupants' behaviour on lighting and blind control systems in Belgium showed 10% saving when occupants' behaviour was accounted for in simulation.

Considering the relevance of buildings' occupants' behaviour on energy consumption in buildings, there is the need for research to focus on determining the actual behaviour occupants an apply this in building energy modelling and simulation towards more reliable results. This can improve energy efficiency in buildings.

2.8.11 Lighting systems

The type of lighting systems in buildings can have a significant effect on buildings' energy demand. The most energy efficient approach in terms of lighting is to maximize daylighting through an appropriate design that avoids solar gains and glare (Arup, 2016). Buildings that are designed to rely only on daylighting during the day will help to save a significant amount of lighting energy in buildings. Krarti et al. (2005) stated that designs that take advantage of daylighting could lead to savings of about 30% of artificial lighting energy. There is now an increased interest in incorporating natural lighting with electric lighting to decrease energy consumption in buildings (Li and Lam, 2001). There will be an increase in energy demand where buildings have to rely on artificial lighting in some spaces during the day.

During nighttime, functional spaces in the building require artificial lighting. There are different types of lamp that can be used in interior spaces and each has their energy requirements. Figure **2-24** shows lamp types and their corresponding energy efficiencies, which the LED lamps have the highest energy efficiency compare (energy saving and CO_2 reduction) to other lamps using in buildings (Sin and Yun, 2010). Therefore, it is highly recommended in order to reduce energy in terms of lighting in buildings.

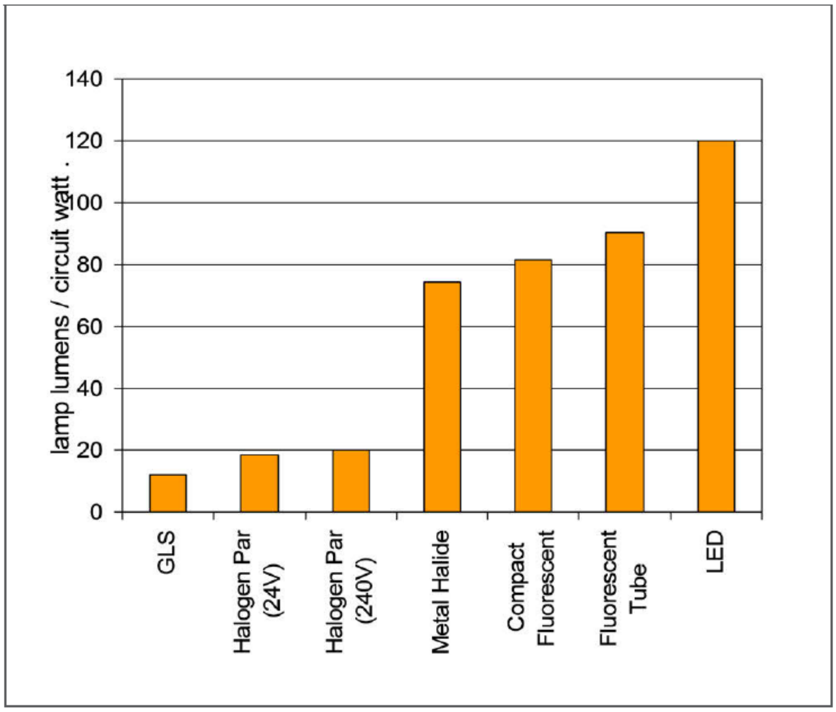


Figure 2-24 lamp types and their corresponding energy efficiencies

Source: (Arup, 2016).

2.8.12 Ventilation systems

There are two main types of ventilation in buildings namely natural ventilation and mechanical ventilation. The type of ventilation in a building can have a significant effect on its energy consumption. Natural ventilation refers to air movement from windows, doors, and cracks in buildings. This was the most common means of ventilation in buildings in the past according to guide to home ventilation report, 2010. There has been a growing interest in maximizing natural ventilation in buildings due to some challenges associated with the use of mechanical cooling systems. According to Liping and Hien, 2011, the advantages of natural ventilation in buildings include a reduction in operational cost, improved indoor air quality and provision of thermal comfort. To improve natural ventilation, Kleiven (2003) suggested that the floor layout of buildings should be kept as simple as possible and with open plan spaces, which offer little resistance to air flows.

Air velocity is an important factor in providing ventilation in buildings. CIBSE recommended airspeed of about 0.1 m/s in winter months and approximately 0.3 m/s in summer months for a balance between building occupants' comfort and indoor air quality (Clancy, 2011).

The depth of the functional space and plan form can have significant effects on natural ventilation. Deep plan form will make buildings to depend more on mechanical cooling and artificial lighting systems (Elaiab, 2014).

Mechanical ventilation involves the use of heating, ventilation and air conditioning systems (HVAC) powered by electrical systems. Heating and cooling systems have major effects on energy consumption in buildings (Chan et al., 2010). Perez-Lombard et al. (2008) stated that HVAC systems are responsible for about 50% of buildings energy demand and 20% of total energy consumption in buildings in the USA. The high energy demand associated with the use of heating and cooling systems to overcome discomfort in buildings has led researches over the past decades to focus on developing advanced technologies and intelligent building systems to significantly reduce energy demand by buildings (Zhao et al., 2016). This study is in line with the global effort to reduce energy consumption in buildings, especially due to the use of cooling systems in residential buildings.

2.8.13 Building design

The design of buildings is a significant factor in reducing energy consumption in buildings. Sozer (2010) stated that a proper design of the building envelope can lead to considerable improvement in energy efficiency and aid the realization of heating and cooling targets. Okba (2005) who seem to corroborate this view stated that appropriate design on the building could lower total cooling demand thereby reducing too much dependence on cooling systems. Aktacir et al. (2010) posited that architectural and physical properties of buildings are the most significant elements that affect space-cooling load. Akande (2010) stated that several residential buildings in some climates are not suitable for building occupants because they were not properly designed.

2.9 Comparison of previous studies and current study

Several studies have investigated sustainable architectural dimensions on buildings in terms of environmental and social aspects. Majority of these studies considered specific or different aspects of the building sustainability. For instance, Cabeza et al, 2010; Ihm & Krarti, 2012; Aldossary et al, 2014; Alaidroos and Krarti, 2015; Dabaieh et al, 2015; Dhaka et al, 2014; Deshmukh et al, 2015 and Mirrahimi et al, 2016 studied environmental sustainability through strong advocacy and recommendation for the adoption energy efficiency measures in building development. Their studies focused on factors such as building orientation, building envelope and lighting. However, other studies centred on socio-cultural aspect of buildings, which is key to achieving energy efficiency (see Hashim et al, 2006; Memarian et al, 2011 and Sobh et al, 2013). The concept of sustainability in architecture aims to achieve a balance between people, environment and cost through buildings. Hence, this study focuses on environmental and social aspects of building development, which will no doubt have significant effect on the economic aspect and people's wellbeing. Table **2-6** shows comparison between some studies for energy efficiency and socio-cultural needs.

Table 2-6 comparison between some studies for energy efficiency and socio-cultural needs

Author	Energy efficiency							Socio-cultural needs
	Orientation	Building envelop					Lighting type	Privacy and family cohesion
		Glazing type of window	Shading	Ground floor	External insulation wall	Roof insulation		
(Ihm and Krarti, 2012)	X	X			X	X	X	
(Aldossary et al, 2014)		X		X	X	X		
(Alaidroos and Krarti, 2015)		X	X		X	X		
(Dabaieh et al, 2015)						X		
(Cabeza et al, 2010)					X	X		
(Deshmukh et al, 2015)					X			
(Dhaka et al, 2014)		X			X	X		
(Mirrahimi et al, 2016)	X	X	X		X	X		
(Hashim et al, 2006)								X
(Memarian et al, 2011)								X
(Sobh et al, 2013)								X
(Nagah et al, 2018)	X	X	X	X	X	X	X	X

Source: Author

The emphasis of majority of the studies on energy efficiency in table 2.6 were on the building envelope focusing on building orientation, window glazing type, floor type, shading and insulation. Only the study of Lhm and Krati (2012) considered the effect of lighting on energy efficiency in buildings. The table showed limited study on the effects of socio-cultural needs on sustainable architecture. Moreover, no study considered energy efficiency in buildings considering both the building envelope and socio-cultural needs. Hence, the need for this study that aims to achieve energy efficiency in buildings by considering both design and socio-cultural factors as current study by Nagah et al. (2018).

2.10 Chapter summary

This chapter presented a brief discussion on sustainability and sustainable architecture, which provides the basis for energy-efficient buildings. Sustainable architecture centered on realizing the broad aim of sustainability of maintaining ecological balance and providing an opportunity for all life forms to survive and flourish. This review showed that energy efficiency in the building is embedded in this goal.

This chapter discussed the importance of privacy in traditional architecture, how it affects the design of buildings in the study context. The major aspects of privacy in traditional architecture are privacy between neighbours' dwellings; privacy between male and female; privacy between members of a family and individual privacy (Mortada, 2003; Othman et al., 2015). Privacy in buildings can be considered at different levels of visual, acoustic and olfactory. The various levels of privacy could be achieved through the design of interior spaces and the building envelope. Furthermore, this chapter highlighted the various principles adopted in traditional architecture to achieve comfort in buildings. These concepts include the use of compact urban form, orientation, building components, shading, and passive cooling. The chapter further compared traditional with contemporary houses in terms of privacy, thermal comfort, and energy consumption. Moreover, this section highlights the important features of traditional buildings regarding privacy and thermal comfort, which have almost disappeared from contemporary houses.

This study focuses on achieving energy efficiency in buildings. Hence, the literature review in this chapter included an overview of energy efficient buildings highlighting the definition and the major approaches to achieving energy efficient buildings for the various climatic zone in the world. This study also summarized thermal comfort concept and discussed the two models for predicting thermal comfort, which are predictive mean vote (PMV), and adaptive method. Another significant aspect of this chapter involves a discussion of factors that affect energy consumption in buildings. The factors presented in this section are climate, building, building orientation, building materials, building envelope, building occupants, behaviour highlighting systems and appliances, ventilation system and building design. All these factors are key to reducing energy consumption and improving thermal comfort in buildings. Nevertheless, it would be difficult to achieve buildings energy target without appropriate occupants' behaviour. Hence, building occupants' behaviour can have a significant effect on energy consumption in homes.

This chapter showed that occupants' behaviour could have a direct or indirect effect on energy consumption in buildings. Emphasizing the significance of occupants' behaviour in terms of buildings energy performance, Hong and Lin (2013) stated that occupant behaviour is among the most significant source of uncertainty in the prediction of energy performance, especially by using simulation tools due to the complexity and uncertainly in occupants' behaviour. Looking at the importance of building occupants' behaviour on energy demand in homes, this section emphasized that an important aspect of energy-related research is to determine the actual behaviour of building occupants and use this for building energy modelling and simulation towards a more reliable result. Hence, both technical issues and excellent operational practice are key to lowering building energy demand.

This chapter has provided a platform for this study by discussing the relevant concept related to thermal comfort and energy consumption in the building. It has reviewed the various means of achieving energy efficiency in residential buildings in a hot climate without disregarding socio-cultural factors. This has revealed the need for this study, which focuses on developing a framework for designing energy efficient dwelling satisfying socio-cultural needs in a hot climate.

3.0CHAPTER THREE: BENGHAZI AS A CASE STUDY

3.1 Introduction

This chapter presents a review of existing data on Libya and Benghazi, the study area. Section 3.2 documented an overview of Libya major emphasis on location, population and climate classification. Section 3.3 presents relevant data about Benghazi, the study context discussing Benghazi climate, Libyan socio-cultural characteristics, and housing types. Section 3.4 focuses on the challenges with residential buildings in Libyan cities. This chapter was concluded with a summary in section 3.5.

3.2 Overview of Libya

This section of the thesis centers on background information about Libya with a major focus on location, population and climate classification.

3.2.1 Location and population

Libya is located in the middle of North Africa. It lies between latitude 200, 340N and 100, 250E (El- Tantawi, 2005). It is bounded on east with Arab Republic of Egypt and Sudan; on the south with Chad and Niger; on west Tunisia and Algeria and on the north the Mediterranean Sea. Libya is the fourth largest country in Africa and has a population of 6 million. Libya has a total land mass of 1,760,000 square kilometers (Daza, 1982). The coastline of the Mediterranean Sea on the northern border is 1,955 kilometers (Amer, 2007). By virtue of its location at the middle of North Africa, it has been a distribution center between central Africa and Europe on one side and between countries to east and west of Libya (Daza, 1982). Figure 2-1 shows the location of Libya on part of the map of Africa.

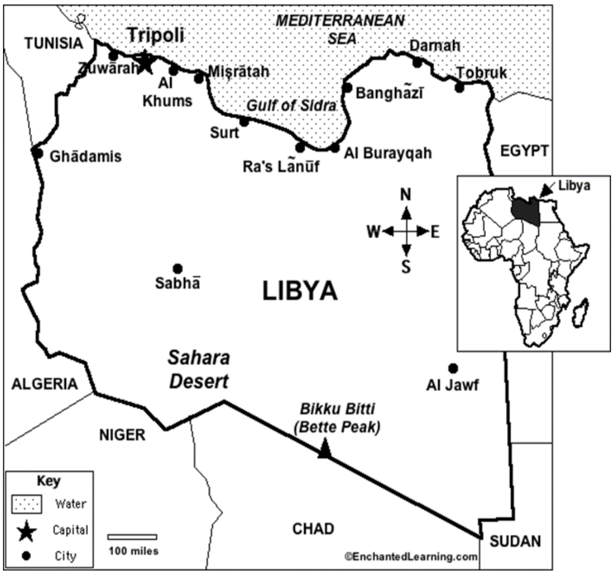


Figure 3-1 the location of Libya on part of the map of Africa.

Source: El- Tantawi (2005)

3.2.2 Climate classification

The climate of Libya resulted from the interaction between the Mediterranean Sea on the North side and the Sahara Desert. The major climatic influences in Libya are the Sahara Desert, the Mediterranean Sea and the mountain region. Koppen classified Libya under three major climates. The first classification is the hot desert climate (BWh) which covers a significant percentage of the mid and southern Libya having a mean temperature of above 180C all year round. The second climatic classification if the hot steppe climate type (BSh) in the northern part while the third climate type is the Mediterranean zone (CSa) in north-eastern Libya on Jebal El-Akhdar (El-Tantawi, 2005). Dioxides (1964) also divided the climate of Libya into three regions, the plain coastal, the mountainous and the desert and semi-desert regions.

3.2.2.1 The coastal region

In this region, the temperature tends to be a bit mild and tolerable during summer due to the influence of the Mediterranean Sea (Emhemed, 2005). The average minimum temperature during the coldest month of the year, January is 7.60C and the average maximum temperature is 16.50C. The temperature in the hottest month of the year, August reaches a minimum of 21.70C and an average maximum temperature of 30.80C.

Daze, (1982) stated that the dominant wind in this zone blows from the north and northwest throughout the year. Emhemed (2005) revealed that the southerly wind (Ghibli), which is always hot and dusty has no significant effect on this region as it is well protected by the mountain chains of Aljabel Algarbe and Alakder.

The average humidity in the coastal region is from 58% to 65% but may be more during summer (June to August) (Emhemed, 2005). The annual rainfall in this zone reaches 300-400mm and can exceed this range sometimes (El-Tantawi, 2005). The rainy season usually starts in the month of October and end in the month of March with the maximum record of rainfall in the months of December and January (Amer, 2007).

3.2.2.2 The desert region

The Libyan Desert has been regarded as one of harshest and most arid in the world. It is extremely hot during the day and cold at night. This region is characterized by very high yearly temperature with a wide difference between day and night and between winter and summer (Amer, 2007). The desert region is mostly hot and dry as rain rarely falls in the winter months (Daza, 1982; Emhemed, 2005). Spring and autumn are affected by the southerly wind (Ghibli) (Pidwirny, 2006). North and north-westerly winds are seen as the most preferable for summer nights owing to their lower velocity which makes them less damaging in winter. The southerly wind and sand storms are more frequent in summer (Amer, 2007).

The average humidity in the desert region ranges from 20% to 59% and the minimum temperature which occur in January is 2.1^{0}C and the maximum average temperature which is always recorded in August is 40.2^{0}C.

3.2.2.3 The mountain region

The mountain region is affected by the desert and semi-desert climate, particularly in the summer months. The temperature during the summer months is usually high due to the southerly wind which blows from the desert bringing in the dust (Emhemed, 2005). The winter months are generally cold in this zone as the temperature can be as low as 00C because of snowfall at the top of the mountains (Amer, 2007).

The average minimum temperature, which occurs in January, is 4.60C while the average maximum in the month of August is 32.50C. The relative humidity in the mountainous zone is fairly lower than the coastal zone making it the best summer zone (Amer, 2007). The average humidity falls between 46% and 74% while the average rainfall reaches 200mm to 400mm and sometimes up to 600mm (Emhemed, 2005).

3.3 Benghazi as the study area

Benghazi is located in northeastern Libya along the Mediterranean Sea and has a landmass of 314km2. Benghazi is the second largest city in Libya with a population of about 631,555. It is the capital of the northern region and has the highest population density of about 2000 inhabitants per square kilometer (Emhemed, 2005). Figure **3-2** shows the location of Benghazi.

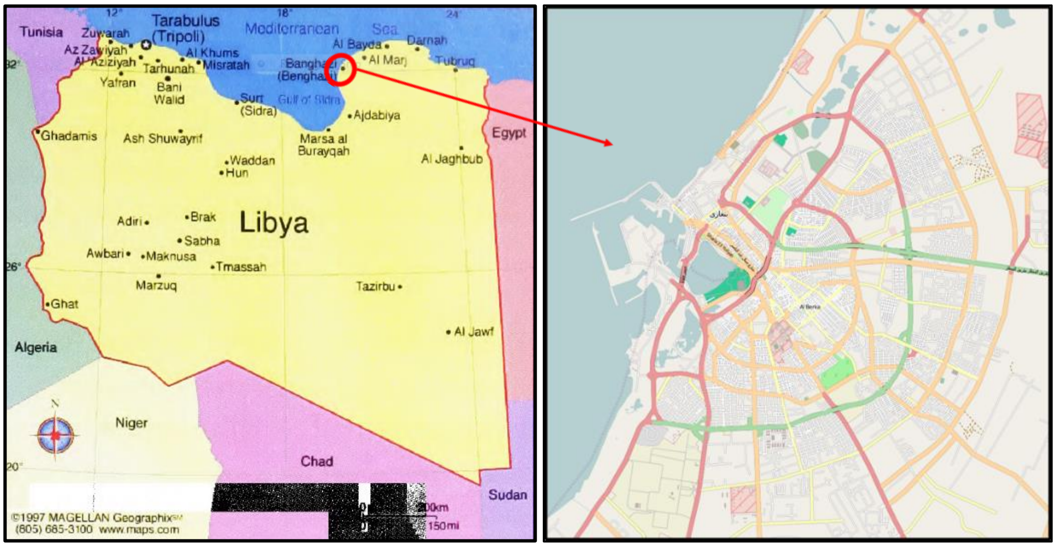


Figure 3-2 location of Benghazi

Source: Emhemed (2005)

Benghazi has been considered a magnet for the migration of people from different regions of Libya because of economic prosperity and provision of job opportunities. This has led to increased population growth and demand for more housing. According to the National Physical Plan, the yearly demand for housing is expected to grow from 24,000 units to 38,000 units between 2000 and 2025 (UPA, 2006; Mohamed, 2013). The increase in population has led to an increase in the construction on new houses leading to a significant increase in energy demand.

3.3.1 Benghazi climate

The climate of Benghazi is characterized by extremely variable conditions of temperature with the annual means decreasing and the annual ranges of temperatures increasing along the pole and low precipitation (Meteoblue, 2018). The Mediterranean climate provides hot summer and mild winter months. The temperature in the day during the summer months ranges mostly from 300C to 350C. Benghazi climate falls under the Koppen classification BSh, steppe hot arid climate. Figure **3-3** shows a world map of the Koppen Geiger climate classification. This corresponds with the coastal classification according to Doxides (1964). Benghazi climate is contiguous with the desert climates of North America, South America and Central Asia (Meteoblue, 2018).

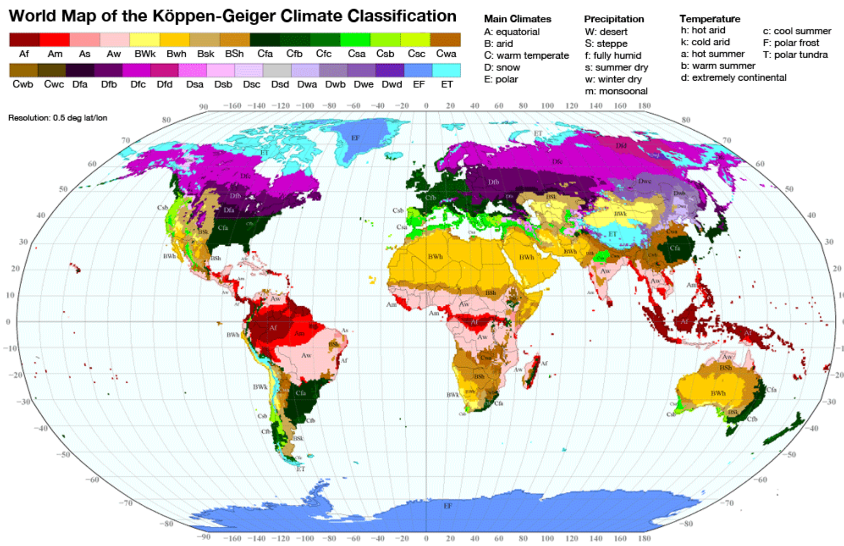


Figure 3-3 world map of the Koppen Geiger climate classification

Bulugma (1964) stated that January has the minimum temperature of 8.80C while August has the highest recorded temperature of 30.10C. Recent climatic data according to Meteoblue (2018) shows that the mean daily minimum temperature occurred in February at 80C while the mean monthly maximum occurred in June, July, and August at 34^{0}C. Figure **3-4** shows the minimum and maximum monthly temperature and precipitation in Benghazi.

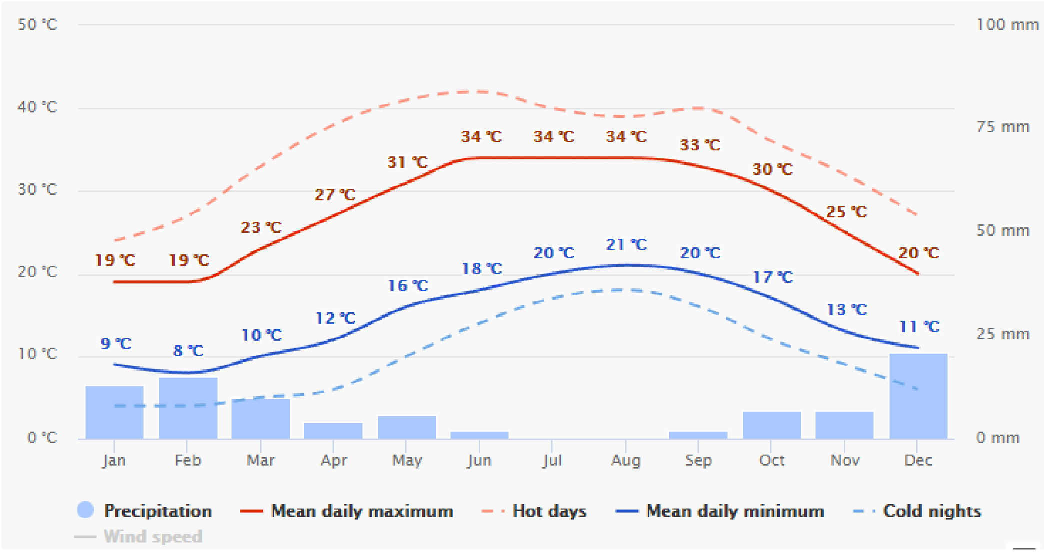


Figure 3-4 the minimum and maximum monthly temperature and precipitation in Benghazi

Source: Meteoblue, (2018)

Benghazi has the moderate annual amount of rainfall less than that of Tripoli of 370mm. The annual average humidity in Benghazi is 58%. Moreover, it suffers less frequent southerly wind (Ghibli), which lead to a significant increase in temperature and decrease in relative humidity (Bulugma, 1964). The major climatic elements that influences the city of Benghazi are wind and rainfall.

3.3.2 Libyan social-cultural characteristics

Cultural characteristics which involve behavioural control and social connections is an important aspect of building design (Emhemed, 2005). These socio-cultural characteristics control and direct the behaviour of the people within both internal and external spaces. Hence, the need to emphasize the social-cultural characteristics of the Libyan in this study.

Up to 97% of the population of Libya are Arab of Barber origin and are Muslims. Islamic ideas have marked effect on the culture of the people of Libya. The focus of the design of urban pattern is a need for privacy and establishing a common bond within the society. In order to promote privacy, the separation between men and women was adopted and incorporated into the organizational concept of the building elements and the grouping of houses of form the urban structure (Al Mansuri, 2010). Emhemed (2005) revealed that courtyard design is significant at improving privacy in houses as it provides an inward-looking building.

The cultural characteristics of the Libyan people have witnessed significant influence from both eastern and western cultures (El-Menghawi, 2004; Amer, 2007). This has led to the adoption of western architectural design which has little characteristics of Libyan culture. Previous researchers have identified the major socio-cultural factors in Libya (Daza, 1986; Shawesh, 2000, Emhemed, 2005; Amer, 2007). These factors are:

- **Privacy:** Privacy is a significant factor in the design of houses in Libya.
- **Separation:** The separation of citizens based on their age, sex and relationship (for example guests) is important within the family unit.
- **Status:** Members of the extended family and elderly people are well respected in the society.
- **Way of life:** There are different aspects to the way of life of Libyan people and these should be considered in the design of interior and exterior spaces.
- **Meal preparation and serving:** Preparation and serving of meals are important aspects in the design of houses. Adequate kitchen and storage space is required to achieve this.
- **Safety and security:** The safety and security of citizens are important priorities in Libya.

Al Mansuri (2010) stated that these socio-cultural factors were properly addressed in Libyan traditional architecture but the majority of them have disappeared due to the adoption of contemporary styles.

3.3.3 Benghazi master plan

According to new housing projects in Benghazi metropolis, Benghazi city consists of three zones namely the old, middle and new zones. The old zone has traditional houses from different historical periods, for example, Islamic, Othman, and Italian colonial while the middle zone consists of majorly from terraced houses, which they were built after Independence of Libya in the 1960s. However, the contemporary dwellings are mostly in the new zone, which have been constructed after the oil revolution. Because of increasing of housing demand, which about 24,000 units to 38,000 units yearly in (2000 – 2025) (UPA, 2006), Libyan government produced a new residential housing scheme for Benghazi citizens, which it forms about 34.67% from a new area for housing projects.

Figure 3-5 illustrates the 3rd generation master planning for Benghazi in 2025, which the light-yellow areas are for a new housing (villa) projects with light residential density.

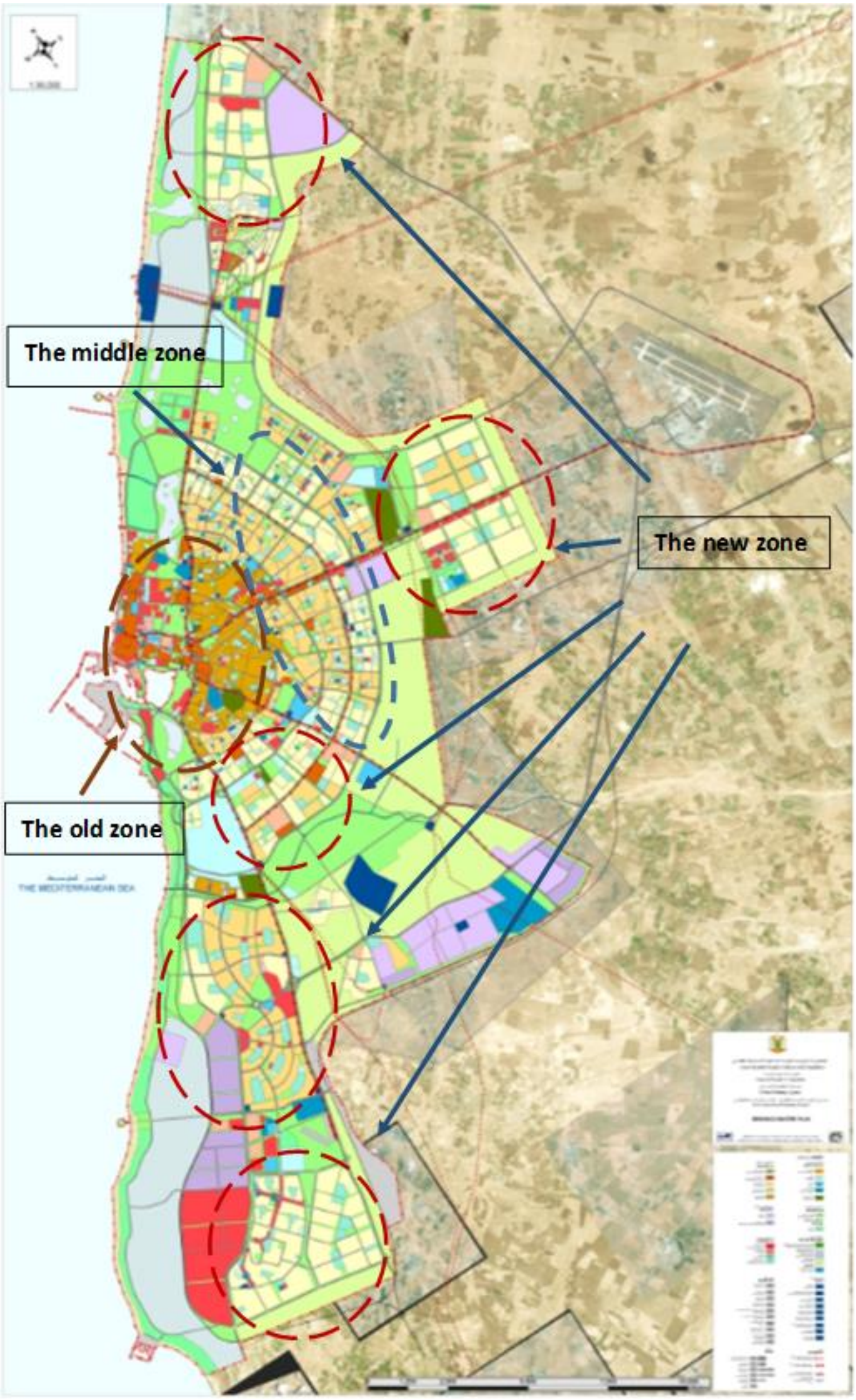


Figure 3-5 the 3rd generation master planning for Benghazi in 2025

3.3.4 Libyan housing types

3.3.4.1 Traditional houses

There are basically two types of buildings in traditional Libyan cities namely one storey and two storey buildings. Both house types are characterized by courtyard and rooms are laid out around the courtyard. Majority of the courtyard houses are attached by neighbours on two or three sides. These courtyard houses have narrow spaces or rooms which are arranged around the central courtyard (Shawesh, 2000). Figure **3-6** shows the floor plan and courtyard of a typical Libyan traditional house.

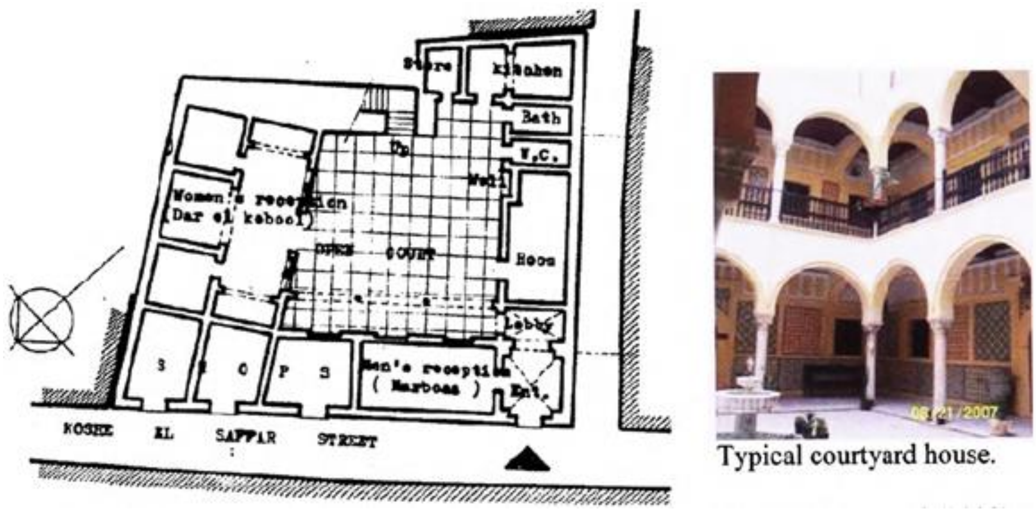


Figure 3-6 the floor plan and courtyard of a typical Libyan traditional house.

Source: Amer, (2007)

The average total floor area of residential houses is approximately 300m^2 and the size of courtyard ranges from about 70m^2 to 100m^2. Courtyard shapes are either rectangular or square (Amer, 2007). The courtyard is usually designed in proportion to the total height of the building in order to meet shading requirements for thermal in summer months. All the rooms are inward looking towards the central courtyard. Rooms depended majorly on openings on the perimeter walls of the central courtyard for lighting and ventilation. The windows on the first floor are very large (obscured using mashrabiya to maintain privacy) to improve daylighting and ventilation. Major emphasis was placed on the beauty of interior spaces than exterior facades. For instance, the highest form of decorations can be found in bedrooms. Shawesh (2000) summarized the functional spaces in a typical traditional house as follows:

- **Main entrance:** The main entrances of traditional houses were designed in such a way that male guests cannot have a visual connection with interior spaces. Male guests are received at the male reception area.
- **Male reception:** The male reception area is located next to the main entrance. Traditionally, the windows are usually located on the external walls and not into the central courtyard. This is to improve privacy.
- **Salah:** This is like a general living room, but it mainly used by women, relatives and family members for relaxation and other activities.
- **Internal (central) courtyard:** This is the functional space in traditional houses as all spaces and activities revolve around it. As stated earlier, the courtyard is usually in a square or rectangular shape.
- **Bedrooms:** bedrooms are located away from the main entrance and majorly on the first floor. The sizes of bedrooms range from 2.5-3.0m to 5.0-6.0m.
- **Kitchen:** Kitchen is usually the ground floor and on the south side of the courtyard.
- **Toilets:** the toilets are located on the ground floor.

Sometimes trees are planted within the central courtyards to reduce the effect of heat and glare. Water pools, wells are awnings are built into some courtyards based on family needs. Loggia is built on one or more sides of the central courtyard to shade spaces from the effect of direct sunlight. Inner balconies are provided on the first floor overlooking the internal courtyard to serve as relaxation areas (Almansuri, 2010).

Courtyards in Libyan traditional architecture has some social functions. The courtyard serves as a tool for encouraging for encouraging building occupants to practice the Islamic teachings on privacy and modesty. The central courtyard which is inward looking has significant influence in this regard. Some of the social functions of the courtyard as identified by Amer (2007) are as follows.

- It improves privacy
- It helps to minimise noise from outside the house
- It enhances family cohesion by providing a place to perform activities for family members, relatives, and friends.

- It provides a safe place for children to play.

The construction of traditional houses in Libyan cities depended hugely on available local building materials. Construction materials such as mud, limestone, sand, stone and sun-dried brick were sourced locally and used in the construction of walls. The walls can be as thick as 70cm. Plants such as pine timber joists, palm tree trunks, and stems and mud were extensively for the construction of the roof. Palm tree trunks were used with a maximum span of about 2.4m. The local building materials were limited in terms of length, width, height, and shape leading to a sense of similarity in the scale and shape of traditional houses (Azlitni, 2009). The walls and roofs of the traditional houses were very thick, and roofs were constructed to a high degree of resistance to heat flow using limestone. The external walls and roofs of traditional houses were always painted white to minimise solar gains.

3.3.4.2 Terraced houses

Terraced houses came up as further development of traditional houses in Libyan cities. These houses were built majorly for low-income earners and can be found in places like El-Hadpah, El-Shargyah neighborhoods. Terraced house is built in one or two storeys high with the courtyard as a common element. Central courtyard is the most popular for terraced houses. The courtyards are usually square in shape and surrounded by rooms. The size of typical terrace houses is nearly 144 square meters. The era of terraced houses brought a major development to the built environment and had a significant impact on Libyan cities, especially in Tripoli. Foreign building materials like cement, reinforcement rods were imported and used for the construction of buildings. Modern construction techniques were also adopted in the construction of buildings.

The walls of buildings were painted in different colours. The roof was constructed with reinforced concrete or clay block and then finished with plain concrete. The houses have less decoration and do not have porticoes at the entrance. Entrance to terraced houses is either located at the middle or corner of the house. There was not unity in style between terraced houses as different types of windows, lintels and arches were used in buildings. Traditional houses were found to be more comfortable for building occupants than terraced houses. Some of the problems identified with terraced houses according to interaction with local architects and planners are summarized below (Azlitni, 2009). Figure **3-7** shows the floor plan, the perspective of terraced houses.

- The size of terraced houses was not suitable for the family size and modern life.
- There was no coherence in the style of houses as there were built in different styles.
- Houses were built in different heights thereby affecting the skyline of the neighborhoods.

Figure 3-7 the floor plan, the perspective of a terraced house

Source: Author

3.3.4.3 Private houses

The discovery of oil in Libya in the 1960's led to rapid socio-economic changes at various levels and in housing development. Hence, the Libyan housing policies were modified to accommodate the economic changes (Azzouz, 2000). Increase in population worsened the existing housing demand leading to an acute shortage of houses for the teeming populace. According to Grifa (2006), the housing deficit in Libya increased at an alarming rate between the 1980s and 1990s. Bukamar (1985) argued that the housing situation in Libya remains inadequate in both quality and quantity after independence in 1956.

Libyan housing development went through several stages before it reached the current position. The major participants in the housing development processes are the public and private sectors. Hence, private houses in Libyan cities are classified under public sector housing and private sector housing. These are discussed below.

a. public sector housing (government housing)

According to El-Menghawi (2004), the public-sector housing is classified into the low-rise apartment and high-rise apartments. The low-rise apartments consist of about 2-4 storeys usually having two flats in every floor while the high-rise apartments consist of 5-12 storeys and can have about 2-3 flats on every storey. The structure of high-rise flats according to Emhemed (2005) is constantly being eroded and argued that there did not properly respond to local climate and neglected the adoption of local building materials. Figure **3-8** shows typical low and high-rise apartments in Benghazi.

Figure 3-8 typical low and high-rise apartments in Benghazi

Source: Aburounia and Sexton, (2004); Azlitni, (2009)

b. private sector housing

Private sector housing is contemporary dwellings built in western type and in different patterns (Azlitni, 2009). El-Menghawi (2004) referred to this housing type as middle-class housing. Private sector housing is characterized by the elements of western architecture. Some of these elements which were adopted in buildings in Libyan cities were not appropriate for the culture of the people. For instance, several buildings were constructed with balconies which not put to use due to privacy issues. The private sector houses are without courtyard which is a major factor in traditional houses. Private sector houses are mainly characterized with gardens and high fences which surround the building.

The spaces within the private sector housing are classified into public, semi-private and private. The ground floor comprises of the semi-public and semi-private areas while the first floor is purely private. Semi-public area includes spaces like main entrance, male and female guest rooms. Semi-private area is spaces such as a staircase, kitchen, living room and bathrooms. Bedrooms are usually located on the first floor, which is the private area. Figure **3-9** shows a typical private sector house.

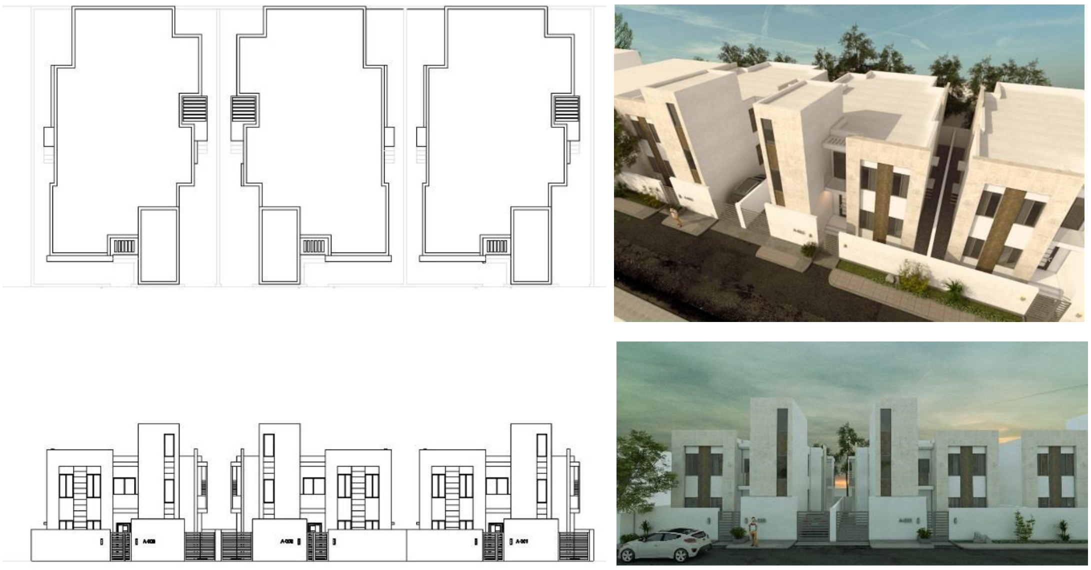


Figure 3-9 a typical private sector house

Source: Author

The majority of private houses in Libya are private sector housing and this represents 60.50% compared with public sector housing. Table 3-1 shows building types in Libya.

Table 3-1 contemporary Building types in Libya in 2006

Private houses types (Contemporary houses)	(%)
Public sector housing	39.50%
Private sector housing	60.50%

Source: Mohamed, (2013)

3.4 Challenges with residential buildings in Libya

Several challenges have been observed with residential buildings in Libyan cities. Some of these challenges motivated the researcher to embark on this research, which aims to reduce significantly them in order to improve the welfare of the people and the environment. These challenges are presented in this section under socio-cultural challenges and thermal comfort and energy consumption in buildings.

3.4.1 Socio-cultural challenges

Several authors have written about housing development in Libya have stated that there are socio-cultural problems associated with contemporary dwellings (Fortea, 1989; Emhemed, 2005; Amer, 2007). These authors argued that the spatial configuration of houses does not satisfy the traditional pattern of family life and the demand for daily living by the people. Some of the problems associated with contemporary houses include lack of privacy, noise and insufficient size of spaces for family activities. Moreover, the social and cultural attributes of the people are rarely incorporated into the design of these houses. El- Menghawi (2004) attributed the challenges with contemporary houses to the effect of westernization, which is gradually changing the appearance of Libyan cities. One of the objectives of this study is to reduce socio-cultural challenges associated with contemporary dwellings in Libyan cities, especially in Benghazi.

In other words, designs of modern houses have been changed away from the concept of traditional houses in which the occupants meet their requirements for socio-cultural and environment aspects (Al Aali, 2006). These contemporary designs are generally seen in high-rise blocks and individual houses (Ahmed, 2012). The majority of buildings in cities, for example, Benghazi, are from houses, according to the National Census (2006) and the Benghazi Planning Study, El- Emara Engineering Consultants, residential buildings represent the highest proportion buildings with 40.61%. Most of these houses have modern western ideas, which were used instead of many cultural and architectural ideas; for example, outdoor spaces in modern villas were used instead of indoor spaces in traditional courtyard houses, big and glassed windows were used instead of high, small openings and concrete and steel were used instead of the traditional building materials (Gabril, 2014).

During different stages of Islamic countries architectural development, the disappearance of characteristics of a traditional house was a consequence of the transformation of the housing design. Nowadays, the houses are re-oriented to the street and have become less responsive to the resident's social situations, privacy, and thermal comfort. The courtyard houses have changed from privacy where the residents positively utilize the inner spaces that are organized around open and sheltered central space, to an exterior space where inhabitants lose a function and role of the house's spatial form (Mahgoub, 2004). Most of the outdoor spaces such as balconies, verandas, and gardens, do not use them effectively because they are not providing privacy and became with time non-functional spaces (Shawesh, 2000).

Benghazi dwellings have distinguished exterior form without considering on interior spaces and relation between outdoor and indoor and orientation. For instance, windows are directed to outdoor space rather than to indoor space (courtyard) as Figure **3-10**, the courtyard was working as a center for family life and a climatic control. Subsequently, air conditioning is used instead mashrabiya which can reduce solar radiations with cool ventilation because it is an enclosed window with engraving wood lattice formed and located on the second floor of a building. In addition, the mashrabiya had another role beside to a climatic role, which is providing privacy to residents. Furthermore, the design of modern houses allows a greater amount of solar radiation to enter through the exterior facades (large glass windows) without considering about the best orientation, this is the type of design is not appropriate to the climate of Benghazi as Figure 3-1.

Thus, windows in Benghazi houses has two negative impacts socially and climatically. In addition, besides of the role of verandas and balconies to providing shading to the building but they are not applicable in Benghazi houses. After inhabitants live in their house, many verandas and balconies are closed or used for storage or not used, because the verandas and balconies cannot provide privacy required to residents in both type of dwellings (apartments, villas) as Figure 3-12 and Figure 3-13.

Figure 3-10 plan of the private house with an outdoor open space surrounding the building

Source: Author

Figure 3-11 using air conditioning and large glassed windows in private houses (villa) in Benghazi

Source: Author

Figure 3-12 abandoned balcony in the villa, Benghazi

Source: Author

Figure 3-13 closed balconies with large glassed windows using air conditioning in apartments, Benghazi.

Source: Author

3.4.2 Thermal comfort and energy consumption

Personal observation and interaction with both building occupants and design professionals in Benghazi show that there is thermal discomfort in houses. Householders find it difficult to live their dwellings without mechanical cooling systems, especially during the summer months. Hence, almost all houses depended largely on mechanical cooling systems to achieve thermal comfort in houses. This has led to huge energy consumption by residential dwellings in Libyan cities. Roaf et al. (2009) stated that energy consumption in buildings in hot climates are mainly due to cooling demand. GECOL (2012) stated that over 75% of energy consumption in Libya is due to cooling load in residential dwellings. In Egypt, energy consumption due to cooling need in buildings ranges from 70% to 80% (Dabaieh et al., 2015). Therefore, buildings are responsible for high energy consumption, CO2 emission and pollution compared to other economic sectors (Sozer, 2010). According to Frontczak (2012) stated that one of the reasons why there is high-energy consumption in residential dwellings is that people spend about 90% of their time indoors. Figure 3-14 shows electricity consumption and distribution in Libya in 2012.

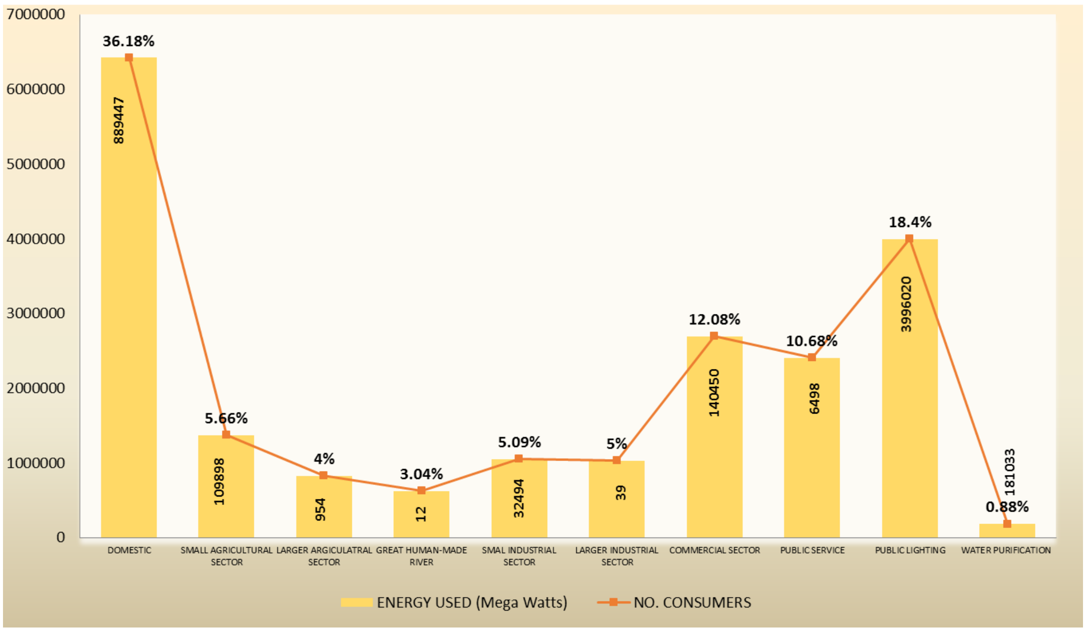


Figure 3-14 electricity consumption and distribution in Libya in 2012.

Source: GECOL, (2012)

3.5 Chapter summary

This chapter has shown that Libya is located in the middle of North Africa. By virtue of its location at the middle of North Africa, it has been a distribution center between central Africa and Europe on one side and between countries to east and west of Libya (Daza, 1982). The climate of Libya falls into a different classification based on different researchers and their basis for classification. According to Dioxides (1964), the climate is classified into three main group which are the plain coastal, the mountainous and the desert and semi-desert regions. Benghazi which the study context falls under the coastal region. The average minimum temperature during the coldest month of the year, January in the coastal region is 7.6^0C and the average maximum temperature is 16.5^0C. The temperature in the hottest month of the year, August reaches a minimum of 21.7^0C and an average maximum temperature of 30.8^0C. The climatic data for other climate zones were documented in section 3.2. The courtyard was the major feature of traditional buildings in all the climate zones.

The courtyard has many advantages in traditional buildings among which are the provision of privacy for family members, enhancement of thermal comfort through the provision of shading, provision relaxation area for all family members and play area for children. Other important features of the traditional buildings include thick walls, small windows at a high level and use of mashrabiya on windows to improve privacy and the used of local materials and construction techniques. These features make traditional houses to be adapted to the local climate and help to meet both socio-cultural and climatic factors related to buildings. The cultural characteristics of the Libyan people have witnessed significant influence from both eastern and western cultures (El-Menghawi, 2004; Amer, 2007). This led to the adoption of western architectural design, which has little characteristics of Libyan culture. This development brought about contemporary building like public and private sector housing, which were designed and built purely based on the western architecture. These buildings lacked the socio-cultural features of the traditional buildings and were not designed based on the local climate.

The adoption of western design and construction approach led to some challenges with building development in the entire Libyan cities. One of these is the lack of socio-cultural features in the contemporary houses. Several authors have argued that the spatial configuration of contemporary houses does not satisfy the traditional pattern of family life and the demand for daily living by the people. Some of the problems associated with contemporary houses include lack of privacy, noise and insufficient size of spaces for family activities.

Another challenge with the contemporary houses is that there were not designed based on the local climate. Therefore, people do not always feel comfortable in their houses. All contemporary houses depend on mechanical cooling systems to achieve thermal comfort in houses, especially during the summer months. This has led to huge energy consumption by residential dwellings in Libyan cities.

This chapter has provided a background to the challenges with building development in the whole of Libya, especially Benghazi, which has been selected for this study. The research aims to reduce significantly these challenges through the production of a framework for designing buildings that satisfy socio-cultural needs and the local climate.

4.0CHAPTER FOUR: RESEARCH METHODOLOGY

4.1 Introduction

This chapter presents an overview of research philosophy and research methodology towards advocating a mixed method. Moreover, it documents the justification of the methods adopted and outlined the research strategy. The entire section is grouped into eleven sections. Section 4.2 introduces the research philosophy in general while section 4.3 presents the research philosophy adopted. Section 4.4 presents an outline of quantitative, qualitative and mixed method research methods leading to choose and justification of a mixed method approach in section 4.5 for this study. Section 4.6 presents a summary of sampling methods. Section 4.7 documents questionnaire design and administration while 4.8 focused on the approach to questionnaire data analysis. Section 4.9 covers interview design and administration strategies. Section 4.10 outlines interview analysis method while section 4.11 centers on measurement and observational survey of existing dwellings. Case study and simulation research approach are discussed in section 4.12 leading to the chapter conclusion in section 4.13.

4.2 Introducing Research Philosophy

There are three philosophies of science namely positivism, realism and constructivism. Constructivism is also known as subjectivism or interpretivism. Positivism and interpretivism are two contrasting extremes while realism lies in between them (Almansuri, 2010). Each philosophical position has different views depending on its ontologies and epistemologies, which defines the research methodology. It might be necessary to present an overview of ontology and epistemology before further discussion on the three philosophies of science.

Ontology refers to the science or study of being and deals with the nature of reality (Blaikie, 2000). It is a system of belief that reveals the investigator’s view on what can be regarded as a fact. Epistemology, on the other hand, deals with can be termed acceptable knowledge in a field of study (Saunders et al., 2009). Epistemology asks questions about how and whether it is possible to gain knowledge of the world (Hughes and Sharrock 2016). Epistemology deals with “the nature, validity, and limits of enquiry”

(Rosenau, 1991, p109). It focuses on the relationship that exists between the researcher and the research participants (Ponterotto, 2005).

Positivism assumes that social reality exists and is controlled by the universal truth. Its ontological assumption is that social phenomena and the meanings applicable to them exist independent of social actors (Bryman, 2012). The positivist approach research by adopting theories and models, which are based on observation and facts using quantitative research methods (Ayikoru, 2009). The proponents of the positivist research approach placed more emphasis on observations that are measurable and lend themselves to statistical analysis. Positivism is a research approach in the natural sciences, which is transferred to the social sciences (Ritchie, 2013).

Realism is another philosophical stance that relates to scientific enquiry. Realism evolved as a dominant position within the post-positivist research paradigm with its proponents. There are two kinds of realism, which are direct realism and critical realism. Direct realism has a view that “what you see is what you get” which means that our experiences through the senses reveal the world accurately (Saunders et al., 2009). Critical realism advocates an independent world external to human that have structures that can be indicated by scientific theories (Alvesson, 2009). Proponents of critical realism argued that human experience is sensations that represent images of the real world and not the things themselves (Saunders et al., 2009). The criticisms argued that observations could be fallible. Hence, observation may not always provide the expected results.

Constructivism is an ontological position, which emphasizes that social actors are constantly achieving social phenomena and the meanings attached to them (Bryman, 2012). Constructivism argued that social phenomena is based on perceptions and resultant actions of social actors related to their existence. Constructivism or subjectivism focuses on the meaning of social phenomena instead of its measurement (Holden and Lynch, 2004). The goal of the subjectivist approach is to understand and explain a problem based on its context (Easterby-Smith et al., 1991). The advocators of subjectivist stance argued that it is baseless to categorize phenomena on the basis of cause and effect as “phenomena are engaged in a process of continuous creation” (Hirschman, 1986, p238). Constructivism advocates that meaning is deep and requires deep reflection to reveal it (Sciarra, 1999). Researchers who advocate constructivist position place more emphasis on participants' view of phenomena and the researcher's interpretations of findings depends on their background and experiences (Creswell, 2007).

4.3 Research Philosophy Adopted

A review of the philosophy of science is key to the research process as it makes the research to consider other relevant possibilities, the enhancement of research capability and the courage that the courage that an appropriate research methodology is adopted (Holden and Lynch, 2004). The previous discussion on the philosophy of science has led the research to the adoption of the combination of positivist and constructivist position for this study. Moreover, the research questions, aim and objectives demand the choice of both philosophical positions. The research methods chosen for this study were based on these philosophical positions. While modelling and simulation approach to the case study of an existing villa in Benghazi and questionnaire survey of householders lend themselves to the positivist stance, case study approach and interview of building professionals follow the constructivist philosophical position. An observation survey of existing residential dwellings in Benghazi lend itself to both the positivist and constructivist views. Table **4-1** shows a guide to the adoption of an appropriate research approach to the philosophical positions.

Table 4-1 Research tactics and their philosophical bases

Research approaches	Objectivism	Subjectivism
Action research		Strictly interpretivist
Case studies	Have scope to be either	Have scope to be either
Ethnographic		Strictly interpretivist
Field experiments	Have scope to be either	Have scope to be either
Focus groups		Mostly interpretivist
Forecasting research	Strictly positivistic with some room for interpretation	
Futures research	Have scope to be either	
Game or role playing		Strictly interpretivist
In-depth surveys		Mostly interpretivist
Laboratory experiments	Strictly positivistic with some room for interpretation	
Large-scale surveys	Strictly positivistic with some room for interpretation	
Participant-observer		Strictly interpretivist
Scenario research		Mostly interpretivist
Simulation and stochastic modelling	Strictly positivistic with some room for interpretation	

Source: Remenyi et al. (1998)

4.4 Research Methods

The research method is the process or technique adopted for the collecting and analyzing research data (Dawson, 2002). The research method is a systematic way of answering research questions (Kumar, 2005; Sridhar, 2009). Researchers have identified various research methods for conducting research in different fields (Yin, 1994; Steele, 2000 Groat, and Wang, 2002). These research methods include case study, experiment, archival analysis, qualitative, quantitative, experimental, correlation and logical argument research. Research methods are classified mainly into qualitative and quantitative (Onwuegbuzie and Leech, 2005). The various research methods help researchers to resolve research problems and to avoid possible inaccuracies is the conduct of research. One or a combination of research methods can be used to conduct research in any field. The combination of quantitative and qualitative research approaches is termed mixed methods research (Johnson, et al., 2007).

4.4.1 Quantitative research

Creswell (2013) referred to the quantitative method as an approach to research where the researcher uses positivist and post-positivist claims for the development of knowledge. Quantitative research method employs natural science experiment to carry out research and deals with counting measuring aspects of social life (Blaikie, 2010). Brannen and Coram (1992) argued that quantitative method deals more with attitudes using large-scale surveys than peoples' behaviour using small-scale surveys. It mainly involves the examination of the relationship between measured numerical variables and the application of statistical techniques (Bryman and Bell, 2015). Three major approaches identified by researchers for conducting quantitative research are desk research, experiments, and surveys (Fellows and Liu, 1997; Creswell, 2003). Survey approach has been used extensively to conduct research in social sciences and involves cross-sectional and longitudinal studies. It makes use of questionnaires or structured interviews for data collection, which aims at the generalization of the sample population to the general population (Babbie, 1990). The questionnaire survey is a research method where respondents are asked the same set of questions. The questionnaire survey is one of the research approaches adopted for this study.

4.4.2 Qualitative Research

The qualitative research method is a constant and repetitive process that involves the simultaneous flow of activities, which deals with data reduction, making verification and conclusion (Miles and Huberman, 1994). Qualitative research approach deals with the description of people, observed behaviours, events and people (Patton, 1990). Polonsky and Waller (2011) recognized images, visions, forms, and structures in media, spoken, printed and recorded word or sound as a qualitative data collection method. Manase (2008) revealed that the qualitative data collection method includes a case study approach, focus group, and direct observation. The data collected using qualitative research approaches are grouped into explanatory and attitudinal data (Naoum, 1998). The qualitative method provides robust data about real-life situations, make sense of people's behaviour and enhance a wider understanding of these behaviours. Nevertheless, the qualitative research method has been criticized for lacking generalizability due to too much dependence on subjective interpretations (Vaus, 2002).

The choice of either qualitative or quantitative or both should focus on achieving reflective finding that responds properly to the research questions. Table **4-2** shows a comparison between quantitative and qualitative research methods.

Table 4-2 a comparison between quantitative and qualitative research methods

Point of comparisons	**Qualitative Research**	**Quantitative Research**
Alternative labels	Constructivist, naturalistic-ethnographic or interpretative.	Positivist, rationalistic or functionalist.
Scientific explanation	Inductive in nature	Deductive
Data classification	Subjective	Objective
Objective/purpose	To gain understanding of underlying reasons and motivations. To provide insight into the settings of a problem, generating ideas and /or hypothesis for later quantitative research. To uncover prevalent trends in thought and opinion.	To quantify data and generalise results from a sample to the population of interest. To measure the incidence of various views and options in a chosen sample.
Sample	Usually a small number of non-representative cases. Respondents selected to fulfil a given quota or requirement.	Usually a large number of cases representing the population of interest. Randomly selected respondents
Data collection	Participant observation, semi- and unstructured interview, focus groups, conversation and discourse analysis.	Structured interview, self administered questionnaires, experiments, structured observation, content analysis / statistical analysis
Data analysis	Non-statistical	Statistical usually in the form of tabulations. Findings are conclusive and usually descriptive in nature
Outcome	Exploratory and / or investigative. Findings are not conclusive and can not be used to make generalisations.	Used to recommend a final course of action.

Source: Amaratunga et al. (2002)

4.4.3 Mixed Method Research

Mixed method research approach means embracing a research strategy using more than one type of research methods. This approach involves working with different types of data and may involve different investigators (Brannen, 2005). Mixed method is a research approach whereby the researcher seems base knowledge claims on pragmatic position (Creswell, 2003). Blaikie (2010) referred to the mixed method approach as studies, which combines both quantitative and qualitative methods either in parallel or in sequence. Mixed method research seeks to integrate qualitative and quantitative approaches towards achieving more accurate and robust information using triangulation (Maxwell, 2005). Using more than one technique or method, known as triangulation, can be by reached using observation, questionnaire, case study and interviews. Furthermore, to achieve specific research aims, triangulation methods were used for data collection and data analysis. Moreover, methodological triangulation can be worked in both qualitative validation and quantitative investigation studies. The research design adopted is both qualitative and quantitative.

Bryman (2001) referred to the mixed method as multi-strategy research implying the adoption of multiple research strategies to complex research question and design. Mixed methods research enables an analytical framework based on literature review and findings from both individuals and groups (Brannen, 1992).

4.5 Mixed Method Approach in this Study

The research aims, and objectives have led the researcher to the adoption of a mixed method research strategy for this study. The view of Johnson et al. (2007, p113) that "mixed methods research is, generally speaking, an approach to knowledge (theory and practice) that attempts to consider multiple viewpoints, perspective, positions and standpoints (always including the standpoints of qualitative and quantitative research)" seems to support this choice. This method has been adopted to provide robust data for this study. Canales (2013) revealed that the adoption of both qualitative and quantitative methods in a study could provide a more accurate and broad data.

This research involved an interview, questionnaire survey, observational survey, case study and simulation research methods. Semi-structured interview instrument was used to collect data from design professionals in Benghazi concerning the design of houses. The design professionals were architects and engineers involved in the design of residential dwellings. The questionnaire survey was adopted to collect data from householders regarding existing dwellings. The observational survey of 72 houses and a detailed case study of an existing villa were conducted to provide robust data on residential dwellings. Building simulation approach was adopted to determine among other things the energy consumption and thermal comfort of existing houses. Table 4-3 presents the method steps of research with used materials and results that will be achieved.

Table 4-3 the method steps of research with used materials and results that will be achieved

Step		Method	Type and material		Results will be achieved
1		literature review	Previous research, articles, journals, and books		Determine and understand the main principles sustainable social- cultural and climatic design
2	Mixed Method	Quantitative	Questionnaires (72 surveys with local residents) in a certain neighbourhood	Asking householders, Observation, and Measurement by researcher	Determine the physical environment and human behaviour regarding to thermal comfort and privacy in houses
3		Qualitative	a semi-structured interviewing with twelve professional people	Interviews with arabic language , recorded by recorder and video,translated to English langage	Determine the fundamental principles of the sustainable environmental design and privacy design in contemporary houses in Benghazi
4		Qualitative	A case study of contemporary private houses in a a certain neighbourhood in Benghazi		Determine,and analyse the nature of housing and their problems which related to privacy dimension.
		Data analysis: Findings,discussion and conclusion			
5		Computer simulation tool	Data collected, analysed and to be used to design a house model, which will be simulated by (Design Builder)	Final stage	Find framework (Design principles and consideration for future development of Benghazi housing) and find the best model for producing a sustainable courtyard house with the implication of building spatial design, orientation,and design of windows of courtyard

4.6 Techniques of Research Methodology

To achieving the aim and objectives, the research methods have been designed for this study based on different perspectives. Traditional and contemporary houses and sustainability of energy-efficient buildings have been considered by Literature review with revealing the gap of the study context. This review led to determine research methodology. The adoption of mixed methods have been designed to approach the research questions, aim and objectives of the study. Quantitative data from observational, measurements and questionnaire survey, simulation of existing case study and qualitative data from interviews with professionals are necessary for the mixed methods approach. The outcomes from the analysis of the several data are basis the proposed framework, which was later examined by using a prototype design. Figure **4-1** the structure of research methods and techniques.

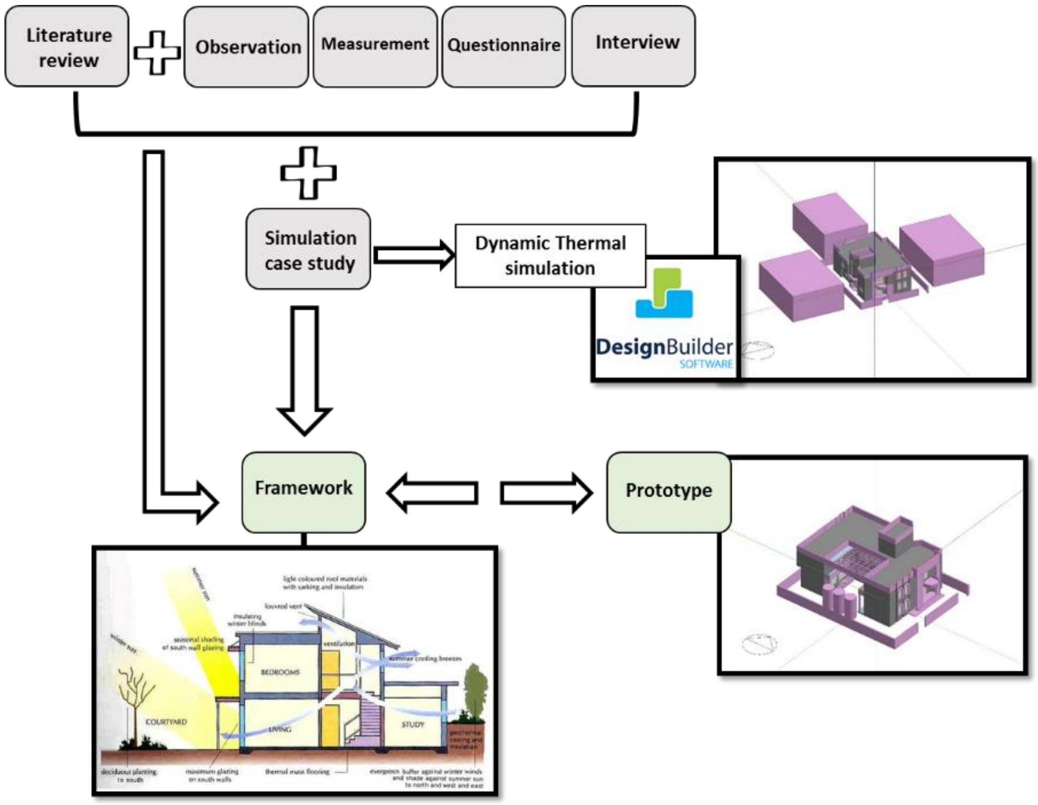


Figure 4-1 the structure of research methods and techniques

4.7 An Overview of Sampling

Sampling is an important step in the administration of questionnaire due to time and cost factors (Babbie, 1990; Creswell, 2003). For a manageable size, it may be possible to collect data from the entire population to address the research question, but for some research questions, it may be difficult or impossible to collect data from the whole population (Saunders et al., 2009). This explains the relevance of sampling for research activities. Collecting data using sampling can enhance the overall accuracy of the research outcome compared to a census as dealing with fewer cases is likely to save time, aids more detailed information and accurate data (Henry, 1990; Saunders et al., 2009). Nevertheless, where the entire population is less than 50, Henry (1990) discourages probability sampling. He argues that the effect of an extreme case may be highly pronounced compared with larger samples.

4.7.1 Random (Probability or Representative) Sampling

With this sampling method, the probability or chance of selecting a case from a population is known and generally equal for all the cases involved. It makes it possible to provide an answer to research questions and realize objectives that necessitate statistical estimates of the characteristics of the whole population from the chosen sample. Probability or representative sampling is frequently applied to survey and experimental research strategies (Saunders et al., 2009). Random sampling is one of the sampling strategies adopted for this investigation. This is due to some of its advantages, which include the possibility to generalize the outcome to the total population (Rea and Parker, 1997), and its relatively low cost in terms of data gathering.

4.7.2 Non-random (Non-probability) Sampling

This type of sampling is mostly applied to qualitative investigations, market surveys, research involving consultation with experts in some fields or for evolving hypothesis that will support future investigations and in situations where there are not adequate sampling structures (Creswell, 2003). It centers on volunteer subjects and those available at the point of contact. It presents some alternative sampling techniques based on the researcher's subjective judgment (Saunders et al., 2009).

4.8 Questionnaire Design and Administration

A questionnaire survey is a research method that involves the distribution of the identical questions to respondents for their views on a research focus (Gray, 2004). Survey method is a method that enables the researcher to generalize from the sample population to the entire population for inferences about the attitude, characteristics or behaviour of the total population (Babbie, 1990). Gillham (2000) argued that the questionnaire survey is one of the most feasible approaches for collecting data from a large group of people. McQueen and Knussen described questionnaire survey as a cost-effective way of involving large sample for the conduct of research to achieve better results.

The accuracy of the questionnaire instrument and the success depend largely on the design of its structure, content and response approach. Hence, necessary precautionary measures must be put in place in the design. These include clarity of questions; flow, length, and structure (Hoinville and Jowel, 1978). The questionnaire design and administration process for this study relied on the research questions, aim and objectives.

The aim of the questionnaire is to collect data on existing dwellings especially in terms of design, energy consumption and thermal comfort. The questions in the questionnaire instruments contained four sections, which are:

Section A – General Questions: This section contains four questions relating to gender, age, family size and level of education.

Section B – House Information: This section has 14 questions and asked questions on house designer, numbers of floors, building location, the total area of all floors (if more than one floor) and a number of openings. Other areas covered in this section include open space and contents, use of open spaces, privacy and level of satisfaction, the effect of inner space on privacy and courtyard style.

Section C – Thermal Comfort Perception: Questions on this section relates to the use of cooling systems, particularly ACs, response to thermal discomfort, respondent's feelings at the time of visit and their expectations regarding comfort.

Section D – Energy Consumption and Human Behaviour: This section covers questions on issues like the type of cooling system, cooling capacity (BTU) of ACs, number of ACs, season cooling systems are mostly used, duration of use per day and electricity bills per day. The detailed questions on the questionnaire survey instrument can be found in the appendix.

Site Selection for Questionnaire Administration

As discussed in chapter three, Benghazi city consists of three zones namely the old, middle and new zones. The new zone was selected for the distribution of questionnaire survey. The new zone is a residential area, which comprises of private dwellings or villas. The third ring road on the North and the fourth ring road on the Southbound this zone. It is defined on the eastern side by road x and on the western side by road y. the area marked out for questionnaire survey is called Al Fwahat neighbourhood. In addition, this site has been selected because it is located along the urban growth of the city and contains old and new villas with age more than 10 years. Furthermore, according to new housing projects in Benghazi metropolis, the area after this site has been planned for a residential housing scheme for Benghazi citizens. The area marked out in yellow as figure 4-2.

Figure 4-2 the selected site for questionnaire distribution.

Most of the houses in this zone have been built for more than 15 years. This is important as it is expected that the building occupants will have adequate experience with their buildings to aid relevant research data. For instance, the trend with energy bills. Buildings in this area represent the majority of typical villas in Benghazi.

According to the Benghazi Planning Study, El- Emara Engineering Consultants (2009), the terms of planning standards for the site, are:

- The width of the main road is 14 m and the second road is 12 m.
- The number of floors is to two floors.
- The area of lands is 500m and 1000m.

- Approximately 60% of the area of land of the villa is building while the 40% is open space.
- The external layout of a dwelling is:
  1. The front area is not less than 3m.
  2. The side areas are not less than 1.5m
  3. The backyard of a villa is more than 3m.

The population of the neighborhood about 2000 P, with approximately 348 villas, and the average height of villas is two floors.

4.8.1 Pilot Survey

A pilot study was conducted for this study to test the suitability and reliability of the questionnaire instrument and the administration approach. A pilot survey is a trial run of the survey instrument that aims to make the main survey easier for the participants to complete (Ahadzie, 2007). Several researchers supported pilot survey before the main survey (Babbie, 1990; Czaja and Blair, 1996). For this study, 60 questionnaires were sent randomly to householders (apartments and villas) in Benghazi to test the instrument. Of the 60 pilot questionnaires, 51 were returned (24 questionnaires from apartments and 27 questionnaires from villas), which represents nearly 85%. No major error was identified during the administration of the pilot questionnaire except that majority of the respondents find it difficult to understand the questionnaire despite that it was in the Arabic language.

Another challenge was with the use of technical terms. This challenge subjected the researcher to think of an alternative means of approaching the main survey. The alternative approach adopted will be discussed under the main survey.

4.8.2 Representative Sample for the Main Survey

Sampling for the main survey is important, as it is not possible for the research to collect data from all the householders in Benghazi. Creswell (2003) argued that it is often impossible to study the whole population irrespective of the research method adopted.

Moreover, sampling is relevant to the conduct of research surveys because of the constraints of time and cost (Babbie, 1990).

The average number of family size in Benghazi is six and the total population of the city is approximately 630,000. The sample size was determined based on this population using Raosoft Sample Size Calculator leading to a recommended sample of 100 people. A margin error of 8% and a confidence level of 95% was assumed for the sample size (Raosoft, 2004).

4.8.3 The Main Survey

As stated earlier, change of the approach to the administration of the questionnaire survey became necessary based on the challenges noticed with the understanding of the questions during the pilot survey. To enhance the understanding of the questionnaire and good responses, the researcher decided to redesign the questionnaire and interpret it in the local language, Arabic to the respondents. The participants were allowed to respond to the questionnaire in Arabic while the researcher recorded their responses. The respondents were happy with the process as they were free to express themselves. Figure 4-3 shows the design and process of questionnaire surveys.

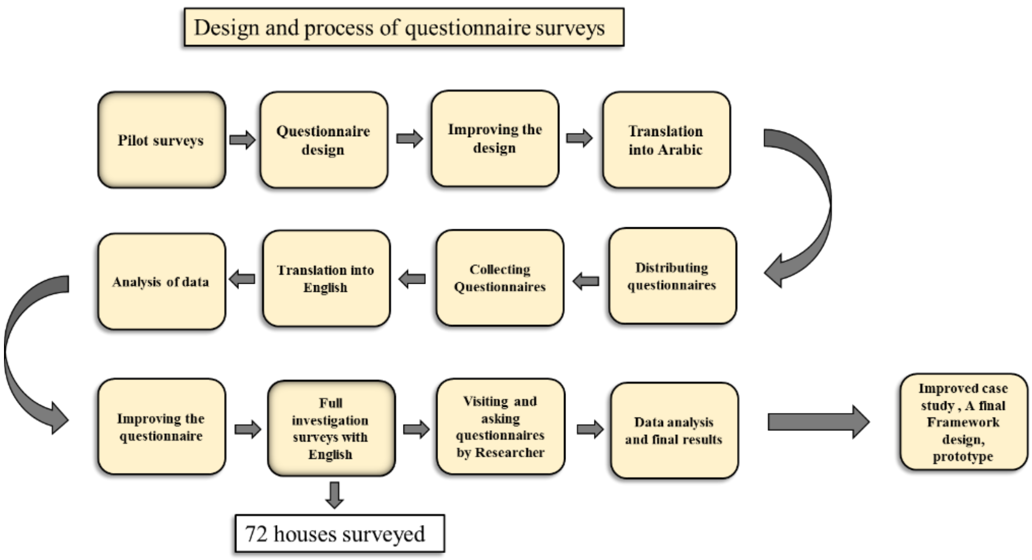


Figure 4-3 the design and process of questionnaire surveys

Privacy and cultural challenges were involved in the administration of questionnaire survey. Among the steps required to minimise these challenges the need to recruit trained research assistants to support the researcher. Hence, three research assistants were recruited to support the questionnaire administration. Contacts were made with householders through the researcher and the research assistants. For those known by the researcher, appointments were made directly while other respondents were recruited through the help of the research assistants and close relatives. Administration of questionnaire was only allowed when a member of the possible respondents knows the researcher, or anyone related to the researcher. The first step involved booking a convenient time. This step was then followed by the visit for the conduct of the questionnaire interviews. Visits to respondents were only possible through pre-booking. Attempts to visits dwelling without pre-booking were turned down. Time and location were pre-arranged. Most visits were in the afternoon and evening while few were in the morning. Due to privacy and cultural issues, visit women were done by the research alone, since female-to-female while visits to men were conducted only when the research assistants accompanied the researcher.

The visit for questionnaire survey included observational survey and measurements of some climatic data. The process involved in collecting data through observational survey and measurements are documented in section 5.2 and 5.4.

Of the 100 respondents targeted based on the calculated sample size, only 72 householders were gotten and responded to the questionnaire during the data collection period. The need for the researcher to be present with the respondents to explain the questions and record responses contributed to this.

4.9 Questionnaire Data Analysis

A set of statistical analysis programs can be used for the analysis of quantitative research data. This includes the Statistical Package for the Social Sciences (SPSS), Microsoft Excel and Microsoft Access. Excel Spreadsheet was adopted for analysis in this study because the researcher is more proficient with it compared to the other statistical analysis software. Moreover, Excel Spreadsheet is cost-effective, as it is free to use and all-in-one software. The process involved in the data collection has been captured in section 5.4 and the data analysis which revealed information about existing villas and the need to improve thermal comfort and reduce energy consumption are documented in chapter five.

4.10 Interview Design and Administration

The sociologists' interest in beliefs and attitudes has developed into the quest to collect data regarding people's feeling (Gilbert, 2001). Interview research approach is a key method of gathering data from individuals about their knowledge and experiences. The interview is among the most widely adopted research method for data collection in quantitative social research (Nunkoosing, 2005).

The interview is a conversation, which aims at gathering information (Berg, 2004). Types of interview approach to data collection are unstructured, semi-structured, structured and group interview (Patton, 1990; Gilham, 2000). Structured and semi-structured interviews were adopted for this study to investigate design professionals' approach to the design of residential dwellings in Benghazi. While the structured interview was applied to section A of the interview relating to the background and general information about the interviewees, a semi-structured interview was used for the questions regarding the intended information from design professionals. Structured interviews are involved uniform questions about the respondents, which requires a specific or direct response. Semi-structured interviews involve specified questions, but the researcher or interviewer is free to use probes to seek further clarification on questions beyond given answers (Babbie, 1998; Gilham, 2000).

As stated earlier, the interview instrument was organized into two sections, section A and B. Section A of the interview contains six questions relating to gender, age, level of education, practice type, years of practice and professional field of respondents. Section B comprises of the main interview questions. Interviewees responded to eight questions relating to housing development in Benghazi. Areas covered by the questions include the effect of social and climatic design on sustainable housing, the influence of western architecture on Libyan architecture and climatic elements in traditional housing design.

4.10.1 Pilot Interview

The pilot interview for this study involved an architect who is highly experienced in housing development, especially in residential buildings in Benghazi. The pilot interview was a means of checking to know whether the structure of the questions and the flow were clear enough and understandable.

The initial focus of the interview was on architects only since they are majorly concerned with the design of residential houses. The pilot questionnaire survey of householders revealed that civil engineers were hugely involved in the design of residential buildings. Hence, it was necessary to involve civil engineers for their opinions.

4.10.2 Representative Sample for the Main Interview

A sample size of at 30 professionals involved in the design of buildings were contacted for their views on residential dwellings in Benghazi. Respondents were selected using a non-probability sampling method. The interviewees were drawn from higher institutions, private practice, and government staff who works in the housing sector. The selection of interview participants depended on their knowledge and experience in a housing development in Benghazi. This is necessary to generate robust data that will support this study and the development of the framework.

4.10.3 Main Interview

To ensure quality data, the possible respondents were first notified about the aim and objectives of this research. Moreover, the interview participants were informed about their roles and how the data that they would provide will be used in the study. The researcher booked appointments with 20 architects and 10 civil engineers for the interview session. The possible interviewees requested for the interview questions to enable them to familiarize themselves with the questions while preparing for the interview. Hence, the interview instrument was given to them before the interview date. The researcher allowed the interview participants to choose the location for their interviews to enable them to feel relaxed and comfortable. Before the interview session, the interviewees were reminded of the need to record the interview and they all consented. Hence, all the interviews were recorded and the data backed-up on the researcher's personal laptop awaiting transcription. All the interviews lasted for about 20 minutes.

Of the 30 professionals initially contacted for the interview, the researcher was only able to conduct an interview with nine architects and three civil engineers making 12 professionals. The analysis of the interview data is documented in chapter five. Figure – shows the Interviews technique.

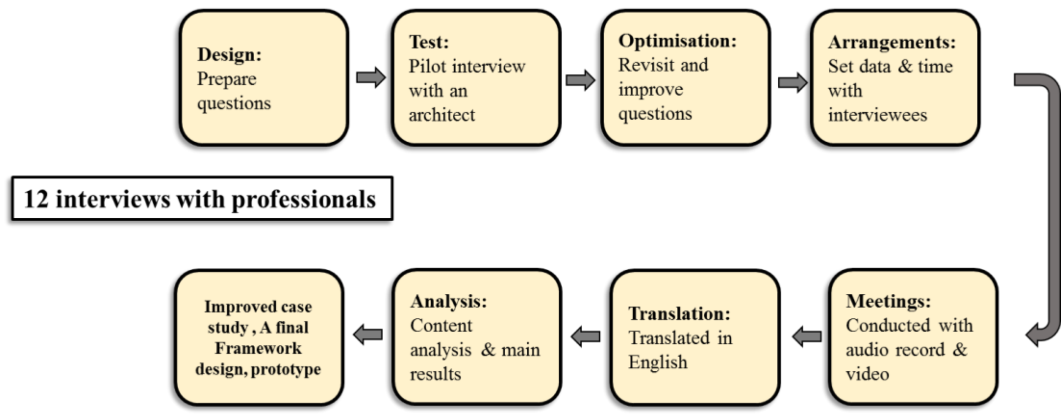


Figure 4-4 the Interviews technique

4.11 Interview Analysis

Content analysis was adopted for the analysis of an interview with professionals. Content analysis is a systematic and replicable method of reducing long words into fewer content categories using coding (Stemler, 2001). Texts in this context include books, essays, discussions, speeches, conversation, and interviews. Wilkinson (2004) argued that Contents analysis provides a relatively systematic and comprehensive overview of the data set and sometimes include quantitative elements. Content analysis is used in this research to explore textual information, which is interviews with professionals in the building industry in Benghazi. The process involved in the analysis of the interview data include interview data transcription, data labeling and referencing, coding, data generalization based on existing theories, identification of key points, development of theories and making a conclusion.

4.12 Measurement and Observational Survey

As discussed earlier, measurement of some climatic elements and observational survey of all 72 houses were conducted during the visit for questionnaire interview. The measurement centered on the level of daylighting in buildings, temperature, humidity and air speed in indoor, outdoor open spaces and outdoor. Daylighting level in buildings was measured using illuminance meter while the researcher used both dry and wet bulb thermometer to measure temperature indoors and outdoors. Procedures for measurement to minimise errors like putting water in the wet bulb thermometer and shaking it was fully observed. Globe temperature for all houses was determined using globe temperature meter while hygrometer was used to measure humidity in indoor, outdoor open spaces and outdoor. A comparison was made between calculated humidity based on dry and wet bulb thermometer readings and direct measurement using hygrometer for some dwellings and the results were the same. Hence, the humidity for other houses visited after this confirmation were measured by hygrometer only. Airspeed for both indoors, open spaces and outdoors locations were measured using an anemometer. The researcher took the minimum and maximum readings and calculated the average, which was used for this study. In open spaces and outdoors, the researcher measured in shaded areas to protect the devices from directed the sun radiation.

Figure **4-5** shows measurement in open space.

Figure 4-5 measurements in open space

Observation involves describing, recording, interpreting and analyzing people's behaviour and the researcher serving as a member of the participants who do not only observe but feel the same experience (Saunders et al., 2009). Observational survey became relevant in this study, which involves determining building occupants' feeling in terms of thermal comfort-based things like activities and level of clothing. Furthermore, it was important to conduct an observational survey of existing dwellings to collect data that can feed into this study. Observational data regarding houses include buildings' immediate environment, the general approach to the design of houses, building characteristics, building typology, building materials, and construction techniques. Despite the advantages of observational research, it has its disadvantages. Table **4-4** shows the advantages and disadvantages of observational research.

Table 4-4 the advantages and disadvantages of observational research

Advantages	Disadvantages
• It is good at explaining 'what is going on' in particular social situations • It heightens the researcher's awareness of significant social processes • It is particularly useful for researchers working within their own organisations • Some participant observation affords the opportunity for the researcher to the experience 'for real' the emotions of those who are being researched • Virtually all data collected are useful	• It can be very time consuming • It can pose difficult ethical dilemmas for the researcher • There can be high levels of role conflict for the researcher (e.g. 'colleague' versus researcher) • The closeness of the researcher to the situation being observed can lead to significant observer bias • The participant observer role is a very demanding one, to which not all researchers will be suited • Access to organisations may be difficult • Data recording is often very difficult for the researcher

Source: Saunders et al. (2009)

4.13 Case Study and Simulation

A case study of an existing villa was conducted to explore the main architectural issues in contemporary houses in Benghazi. "Case studies are analyses of persons, events, decisions, periods, projects, policies, institutions, or other systems that are studied holistically by one or more methods" (Thomas, 2011, p. 513). Wedawatta (2011) revealed that the case study approach is popular with research that involves the how and why questions. Case study research method has the capacity to help investigate minute details and depth on specific phenomena (Flyvbjerg, 2006). In addition to choosing Benghazi as a case study for this research in terms of context, a case study of a villa was necessary for data regarding typical contemporary residential dwellings. The purpose of the case study villa was to help the researcher to model the building and conduct a dynamic thermal simulation to determine among other things the level of thermal comfort and energy consumption in contemporary buildings.

The adoption of dynamic simulation software for exploring energy demand and thermal performance of the building is on the increase. Computer modelling, and simulation software are significant analytical tools for the evaluation of building design (Samaan et al., 2016). Building simulation was adopted for this research to study a typical villa in Benghazi for its performance especially in terms of energy consumption and thermal comfort. This study uses DesignBuilder as a modelling tool, which incorporates EnergyPlus as the simulation engine. The details about DesignBuilder, EnergyPlus, and the weather data for the simulation of the selected case study are presented in chapter five.

4.13.1 Overview on DesignBuilder and EnergyPlus

Computer simulation programs are relevant to determining the comfort level and energy performance of both existing and new buildings. There are many building simulation programmes, which are available, worldwide. These include Ecotect, DesignBuilder, DOE-2, Energy Quest and TRACE (Fasi and Budaiwi, 2015). This study used DesignBuilder (DB) as Graphical User Interface (GUI) to model an existing villa in Benghazi, which has been selected as a case study for this research. The study used EnergyPlus is a simulation engine to determine thermal comfort and energy consumption of the existing building and to conduct possible improvement on it. EnergyPlus was developed by the American Department of Energy (DOE) for whole building simulation. EnergyPlus has passed three different test (comparative, analytical and executable) tests to comply with industry requirements for building simulation (Dabaieh et al., 2015). DB has been chosen for the analysis of the case study for some reasons. DB has a power database for the evaluation of energy performance of buildings (Tronchin and Fabbri, 2008). It consists of abundant building material template for ease of modelling and energy analysis (Wailowski and Reinhart, 2009). DB, which is incorporated, with EnergyPlus as a simulation engine has high capability to estimate energy use, access visual comfort through elaborate daylighting analysis (Fasi and Budaiwi, 2015). Some of the distinctive features of DB are:

- Contains a wide range of weather data for many locations in the world.
- Use up-to-date international standards such as ASHRAE, CIBSE, and other best practice reference data.
- Used advanced natural ventilation tools and detailed HVAC systems
- Provide controls for solar shading, glare and electric lighting
- Offers daily, weekly, seasons and annual cooling and heating calculations.

4.13.2 Case Study Selection

The case study villa was selected for an in-depth study regarding existing dwellings for some reasons. These include age, a typical design, and majority of building typology.

The villa was built in 1999, which is over 15 years. The researcher expects that since the owner has used the building for this number of years; they would be able to provide sufficient data about this building, which represents other villas in this zone. The expected data include energy consumption, thermal comfort, and privacy over the period of use.

The building represents the typical design of a villa in Benghazi. The size of the plot is 500m^2, which is typical of the size of plots. It has two floors, ground and first of total area of about 400m^2. The ground floor is for living while the first floor is for sleeping.

There are several residential building typologies in Benghazi. The selected case, villa represents most of residential building typologies.

4.13.3 Improved case study

This method is adopted to investigate possible improvements that can be made on the existing case study through changes in building materials specifications, construction techniques and alternative design approaches.

The existing building served as a base case model for the improved case study. Improvements were made based on selected parameters, which are orientation, windows, external walls, floor, roof and lighting. Changes in building materials and construction specifications were informed by literature review, interviews with design professionals and questionnaire interviews with householders. Moreover, selections were made to reflect the climate and socio-cultural factors, which are strong design requirements in the study context (see El-Fortia, 1989; El- Menghawi, 2004; Emhemed, 2005; Amer, 2007).

The simulation results of the improved case study are expected to guide the researcher in the development of the proposed framework and the prototype design. Chapter 6, section 6.3 presents details on the improved case study.

4.14 The proposed framework

Rouse (2015) defined framework as a structure that aims to provide guidance for developing a system in to meaningful and useful resource that is more elaborate than protocol and more prescriptive compared to structure. Previous studies have revealed two types of framework, which are theoretical and conceptual frameworks. Green (2014) the development of theoretical or conceptual framework could form the main objective of a research. This is in line with the goal of this study which aims to produce a framework for designing energy efficient dwelling satisfying socio-cultural needs in hot climates. See chapter 7, section 7.2 for an overview of framework.

The proposed framework will be produced base on the finding's measurements, observational survey, interviews with design professionals and both existing and improved case studies. Simulation studies of the existing and improved case studies, which is expected to reveal important design principles and building construction and material specifications for energy efficient buildings will support the development of the proposed framework.

The proposed framework aims to guide design professionals to produce energy efficient residential buildings in hot climates, especially in Benghazi, the study context. Design professionals and other buildings stakeholders are expected to apply the design principles, building materials and construction specifications identified through the research findings to promote and design energy efficient residential buildings.

4.14.1 The prototype design

The prototype design approach was adopted to test the proposed framework for designing energy efficient dwelling satisfying socio-cultural needs in hot climates. It was developed based on the research findings from literature review, field investigation, simulation study of the existing villa and the improved case study. The model aims to highlight relevant energy efficiency design strategies including courtyard design, which can serve as solutions that can be applied to buildings in hot climates, especially in Benghazi. Moreover, it was envisioned to demonstrate the application of the proposed framework as it adopts the relevant steps identified in it. The proposed prototype design is expected to serve a baseline, which could help design professionals to design energy efficient residential buildings in hot climates. The proposed prototype was modelled and simulated in DesignBuilder to determine its performance compared with the existing villa and the improved case study. The details on the proposed prototype courtyard design is presented in chapter 7, section 7.5 of this thesis.

4.15 Chapter summary

This chapter presented an overview of research philosophy covering positivism, realism, and constructivism. The various philosophical views were highlighted based on their ontologies and epistemologies. This led to the choice of both positivist and constructivist positions for this research. It was clear that the researcher's philosophical assumptions affect how research should be conducted and the role of the researcher during the research process.

Quantitative, qualitative and mixed method research were discussed, and the research method advocated at all the research stages were further presented in detail. Moreover, justifications were given to support the choice of a mixed method research approach towards fulfilling the research objectives.

The method adopted for this study were questionnaire survey, interview, measurements, observational survey, and simulation. This chapter outlined the process and tools involved in the data collection for all the methods. A combination of content and statistical analysis using Excel Spreadsheet were advocated for the analysis of quantitative and qualitative data.

5.0CHAPTER FIVE: FIELD SURVEY DATA ANALYSIS AND DISCUSSION

5.1 Introduction

This chapter documents the analysis of the field survey conducted in Benghazi, the study context. It involves an observational survey of existing buildings, a questionnaire survey of householders and interviews with professionals. Section 5.2 presents the findings from an observational survey conducted on a survey of 72 households while section 5.3 documents findings on the survey of a specific household. This was necessary because the building shows most of the challenges in other buildings in terms of privacy, energy consumption and thermal discomfort. Section 5.4 outlines the findings from the survey of existing residential buildings. Section 5.5 centered on the findings from professionals, which aims to produce data on existing buildings, and possible improvements that can be made. Chapter summary in section 5.6 concludes this chapter.

5.2 Observational survey of existing buildings in Benghazi

The research conducted an observational survey of 72 households in Benghazi. Common problems regarding the design of buildings in terms of indoor and outdoor spaces were observed. Privacy issues were the major challenges with the use of outdoor spaces. Moreover, the design of most outdoor spaces did not consider sitting area. The problems observed with indoor spaces include excessive use of electrical equipment, use of drapes on windows leading to the use of artificial light during day and thermal discomfort and energy consumption in indoor spaces.

Figure 5-1 shows a typical narrow street with cars parked outside people's residents. There are streets that are almost double the size of this. Cars are parked outside to provide spaces in the compound where people can relax. There are no trees on streets to provide shading and improve cooling for cars and people. Carports within the compound are sometimes used are relaxation areas because some households do not have private and shaded areas within their compounds.

Figure 5-1 a typical narrow street with cars parked outside houses and a carport is using as relaxing place.

Figure 5-2 shows a picture of a typical wide street. Despite the fact that the street is very wide, sometimes nearly 20 meters, the houses are too close. The closeness of houses hinders privacy between dwellings. Hence, households find it difficult to open their windows for ventilation purpose. Moreover, most households cannot relax within the open spaces of their houses due to privacy issues.

Figure 5-2 a typical wide street in Benghazi.

Figure 5-3 (a) and (b) show balconies that have been abandoned by households because they do not provide privacy for the owners. Some balconies were converted to interior spaces as in figure (b).

Figure 5-3 : (a) abandoned balconies, (b) converted balconies

Some households use vegetation to provide shading in open spaces. This vegetation as shown Figure **5-4** do not meet their requirement for privacy. Hence, tall walls are erected next to them for more privacy as shown below. Furthermore, households use ceramic tiles in open spaces with contributing to thermal discomfort in shaded areas. People find it difficult to use the area covered by vegetation due to reflection from the ceramic tiles.

Figure 5-4 high walls surrounding buildings, using ceramic tiles in outdoor open space

Figure 5-5 shows a tree in an open space, which should be an ideal space for the household to relax but have been abandoned because it did not provide adequate privacy. Households require spaces that provide both privacy and shading. Hence, they use narrow open spaces that provide both shading and privacy.

Figure 5-5 abandoned seating places in house’s open spaces

Figure **5-6** shows an abandoned garden which was previously used as a relaxation area. After the villa shown was erected, the owner of the villa asked the household to remove the tree used to shield the garden from the villa. The reason for this according to the owner of the villa is that is hindering sunlight and the good view among other reasons. Hence the owner of the garden was forced to remove the tree. The garden was abandoned after the tree was removed because there was privacy any longer. The household later closes the terrace to use as a relaxation space instead. They were not happy with this because of thermal discomfort, lack of good views and inability to carry out some activities having a barbecue on the terrace.

Figure 5-6 an abandoned garden

Figure 5-7 shows an open space which has not been properly put to use by the households for many reasons. The open space was not considered during the design of the building. Hence, there are challenges with the dimensions and the location. It is too narrow and located far away from the living room and the kitchen. Though it was cool according to the household, it is majorly used for drying clothes and storing items.

Figure 5-7 an abandoned open spaces

There are challenges with the use of drapes, privacy and ventilation are buildings as shown in Figure 5-8. Drapes are left closed all day for privacy, which has a negative effect on ventilation as this affect fresh air coming into the building.

Figure 5-8 closed drapes in different rooms

There is excessive use of electrical equipment and artificial lighting by households. Artificial lightings are used all day due to inadequate daylighting in buildings because of the use of drapes. These can be seen in Figure 5-9. In addition, excessive use of ACs is also a thing of concern in households. Some people use high capacity ACs meant for public spaces for residential buildings.

Figure 5-9 Excessive use of ACs

5.3 Detailed observation of a household

This household was chosen for detailed observation because it shows most of the problems in other buildings in terms of privacy, energy consumption and thermal discomfort. The researcher visited this household around mid-day to observe the various issues mentioned earlier.

The villa consists of two floors, ground floor and first floor having a total area of 420 m2.

Figure **5**-**10** shows the ground floor plan. The available open spaces around the building are indicated on the ground floor plan. The open space contains a swimming pool, sitting area, and parking spaces.

The researcher observations about indoor and outdoor spaces are presented in the next section.

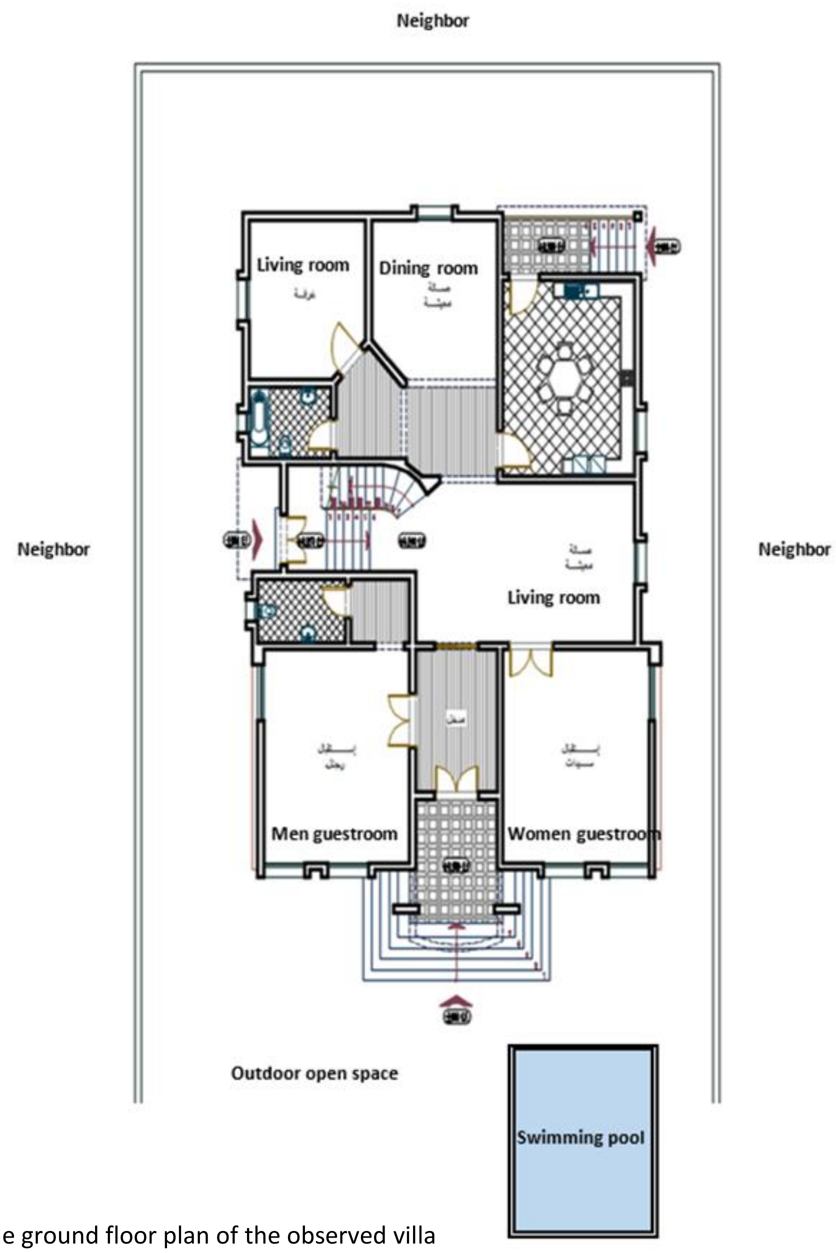


Figure 5-10 the ground floor plan of the observed villa

5.3.1 Outdoor spaces

The households have some challenges with the use of the swimming pool and the sitting area. The swimming pool was abandoned after the building on the next plot was built and there was no longer privacy for the owner. The available trees and shrubs did not provide adequate shade and privacy for the users as shown in

Figure **5**-**11**. It shows some trees planted at the center of the open space instead of along the fence to provide privacy for the households.

Figure 5-11 trees and shrubs did not provide adequate shade and privacy and planted at the center of the open space

The need for sitting in a shaded area with adequate privacy was not considered in the design of the building. The only available space with proper shading as can be seen in Figure 5-12 is exposed to the next neighbour in terms of privacy. Hence, it is only used on a few occasions, especially when the neighbours are away.

Figure 5-12 a shaded area is exposed to the next neighbour

5.3.2 Indoor spaces

The design of the villa is majorly open-plan as shown in Figure 5-13. This affects thermal comfort and energy consumption in the building. This is because ACs have to work continuously to provide cooling for the connected spaces. Although large windows were provided for the building, the use of drapes hinders natural lighting in indoor spaces leading to excessive use of artificial lighting even during the day as shown in Figure 5-13.

Figure 5-13 the design of the villa is open-plan, large windows with drapes and excessive use of artificial lighting

5.4 The questionnaire survey

The questionnaire survey aims to generate data from households in terms of the design of houses, open spaces, the perception of comfort and energy consumption in buildings. The purpose of the questionnaire to produce information that will form part of the proposed framework for the design of residential buildings in terms of privacy, energy consumption and thermal comfort. Research has revealed that it is difficult to achieve the sustainability agenda without considering users participation (Noguchi and Hadjri, 2009).

The questionnaire was distributed randomly to 72 households in Benghazi neighborhoods. The researcher could not distribute the questionnaire to the households to fill in on their own, as it would be difficult for them to understand the content. Therefore, the researcher needs to stay with any particular respondent to explain the questionnaire and record the response. Measurements and observational survey were carried out along with the questionnaire. The survey was conducted in August during vacation time. Hence, it was difficult to get a response from more than 72 households. The response, measurement, and observation were carried out in the afternoon with most respondents. This is because, since the holiday period, respondents needed the morning period to sleep and were only available in the afternoon. The 72 houses were labeled from H1, H2, H3, and H4… H72, which the householders for H1 to H42 were men while the householders for H43 to H72 were women.

The questionnaire survey is divided into six sections:

Section 1: This section presents the general demographic data about the respondents. These include age, gender, and level of education.

Section 2: This section gives brief information about buildings in terms of the designer, area of plot, number of floors, openings, and balconies.

Section 3: This section documents Information about open spaces, which include type, area, content, and level of privacy.

Section 4. This section presents information about households' perception of thermal comfort. The areas covered include ACs cooling set point, the perception of comfort during the time of visit and households' response to thermal discomfort.

Section 5. This section gives information on energy consumption and human behaviour within dwellings. It covers issues like type, number, and capacity of mechanical cooling systems, season and time of use of mechanical cooling systems and average monthly electricity bill.

Section 6: This section was required to gather data from the respondents that may not have been included in the questionnaire.

5.4.1 General Information about Households

The data collected under this section covers the gender, age, level of education and the number of people living in the building.

- **Gender and age of householders**

The data collected on the gender of participants aim to discover their perception of the design of houses and outdoor spaces regarding the layout of floor plans, level of privacy, thermal comfort, and energy consumption. Traditional approaches to wearing clothing by male and female affect the level of thermal perception by both genders. This is important as men and women respond differently to the cooling/heating set point. 42 respondents were male representing 58% while 30 respondents were female representing 42%. Table **5-1** and Figure 5-14 show number and percentage of the genders.

Table 5-1 gender of householders

Gender	Male	Female	Total
	42	30	72
	58%	42%	100%

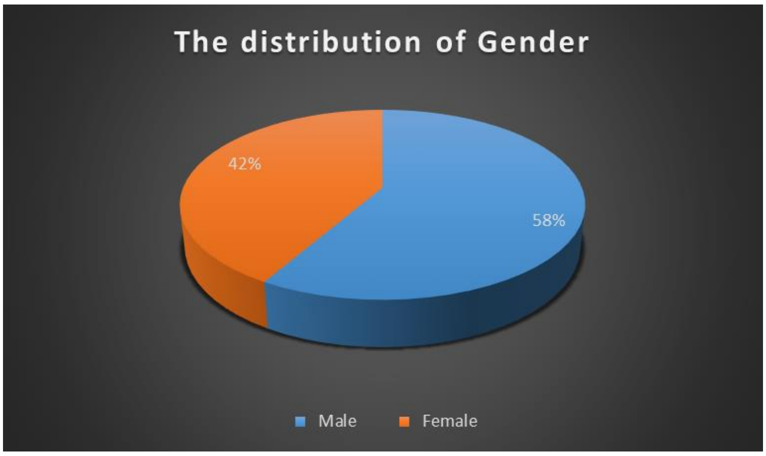


Figure 5-14 the percentage of gender

The age of all the participants was grouped into 10 years interval starting with 31-40 to 71-80. The question on age was intended to study where there are differences in terms with the views of households on the design of houses, comfort perception, energy consumption and the level of privacy in indoor and outdoor spaces. The highest group occurred at 41-50 representing 42% while the lowest in group 71-80, which represents 10%. Table **5-2** shows the age distribution of participants while Figure 5-15 presents the percentage of the age distribution.

Table 5-2 the age of householders

Age	31-40	41-50	51-60	61-70	71-80	Total
	11	30	11	13	7	72
	15%	42%	15%	18%	10%	100%

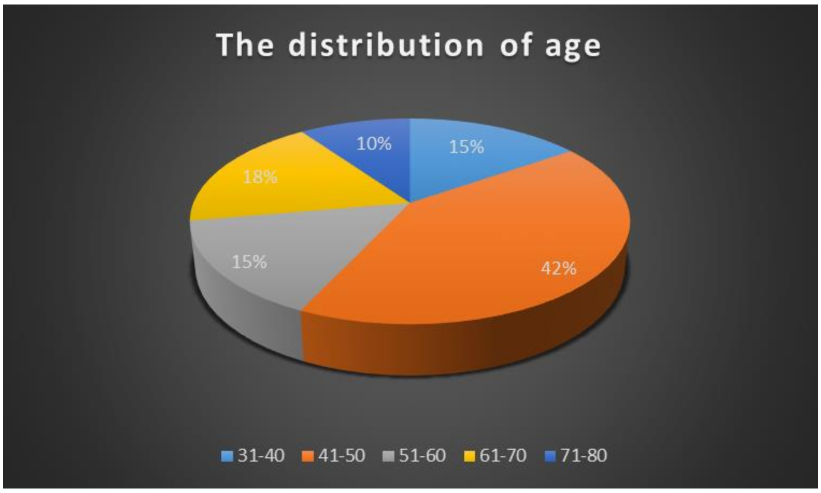


Figure 5-15 the percentage of age

- **Level of education**

This part of the survey was to study the effect of the level of education of the households on the questions relating the design of buildings, open spaces, the perception of thermal comfort and energy consumption in buildings. The level of education of the participants was grouped into undergraduate, postgraduate and others. The various percentages representing these categories are presented in Figure **5-16**.

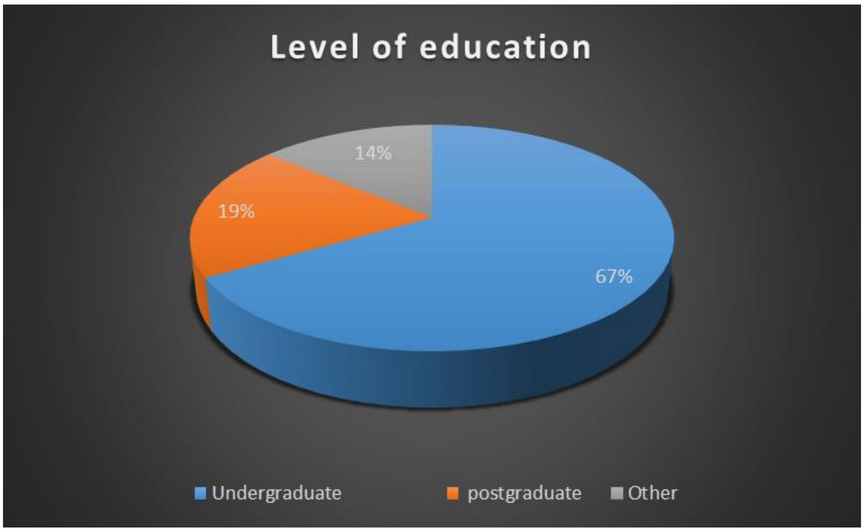


Figure 5-16 the level of education

5.4.2 House information

- **House designer**

Households got the design for their buildings were from different sources. The various sources include architects, engineers, and contractors. Some households copied the design of their neighbours or friends (Repeated Design) while some respondents do not the source of the design of their buildings (Do not know). The question in this section is to help the researcher to determine the effect of the designer on the application of the principles of design especially in terms of the climate. Civil engineers designed most of the buildings, which represents 46% of the total number of buildings. This confirms the reason why the researcher selected two civil engineers to be interviewed alongside with architects for data on the design of buildings in Benghazi. Architects designed only 17% of the buildings. Figure **5-17** presents the distribution of the designers of buildings.

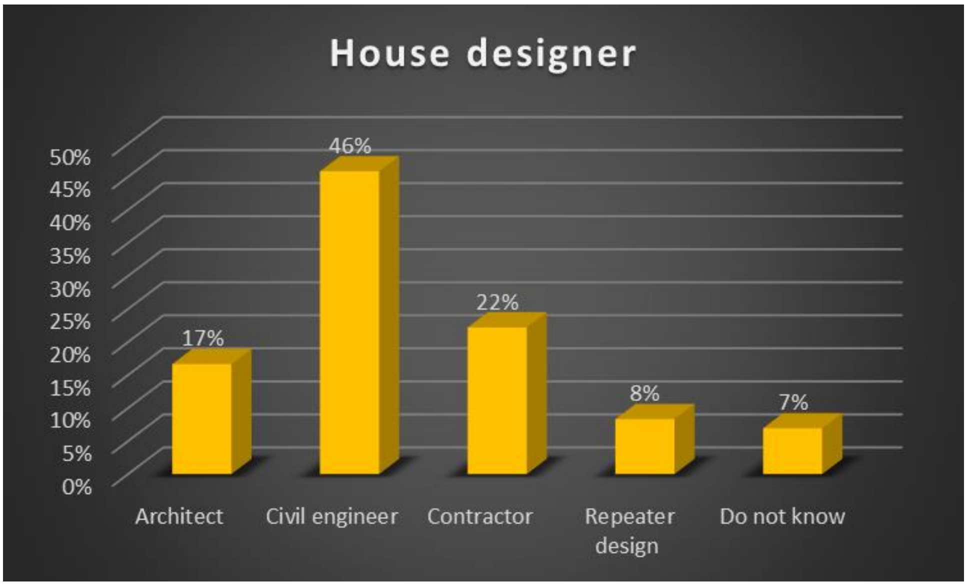


Figure 5-17 the distribution of the designers of buildings

- **Area of plot and number of floors**

A standard plot according to land allocation in Benghazi is 500m^2. However, according to the survey revealed that some respondents own one or more plots for various reasons. While some bought more two plots for their personal use, others bought two or more, gave out or sold part of their plots.

The government determines the number of floors for each house. Majority of houses are a villa, two-floor buildings, while very few houses are one-floor dwellings. The survey revealed that the average size of the ground floor of villas is nearly 300m^2. This means for a standard plot, 200m^2 is left for open spaces. This may not enough for parking spaces, sitting area, and circulation space. Furthermore, the floor size has a negative effect on the level of privacy, as the buildings will be very close to neighbours. Moreover, most buildings are sited at the center of the plot making it difficult to have reasonable open spaces.

- **Number of openings and balconies**

The number of windows, doors, and balconies on the different facades of the 72 buildings were recorded during the survey. Studies have revealed that it is necessary to minimise the location of windows on the East and West facades in order to reduce heat gain (references). The survey aimed to know the location of windows and their implications on comfort and energy performance of the buildings. Moreover, this will confirm to an extent whether professionals involved in the design of buildings or not. Table **5-3** and

Figure **5**-**18** present the summary of the location of windows, doors, and balconies of the different facades of the buildings surveyed.

Table 5-3 numbers of openings (windows, doors and balconies) in each façade

	Windows	Doors	Balconies
North façade	158	65	52
East façade	302	81	72
West façade	179	79	41
South façade	222	57	45
Total	861	282	210

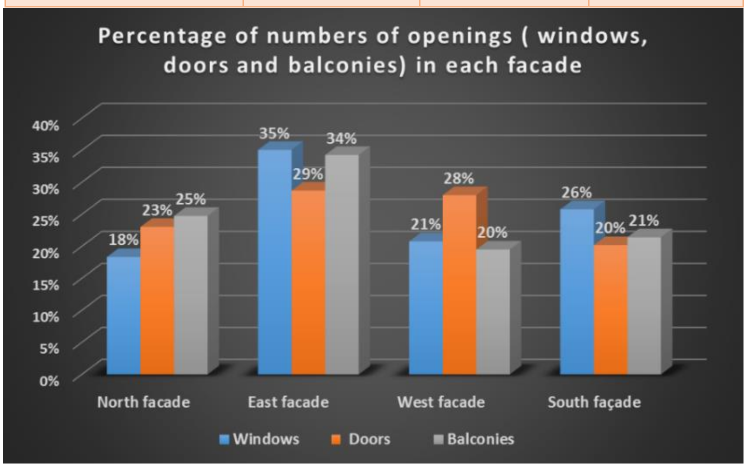


Figure 5-18 the location of windows, doors, and balconies of the different facades of the buildings.

- **Windows**

The survey of the 72 houses revealed that 158, 302, 179 and 222 windows were located on the North, East, West and South facades respectively. The highest number of windows were located on the East elevation. This represents 35% of the total number of windows. The lowest number of windows recorded for the North façade, which is 158 windows representing 18% of the total number of windows. To minimise energy consumption in buildings it is expected that the majority of the windows should be located on the North and south facades. This is not the case for the North elevation, which has fewer windows based on the survey. Table **5-3** and

Figure **5**-**18** show the distribution of windows on the four elevations of the 72 buildings.

- **Balconies**

The surveyed showed that 52 (25%) balconies were sited on the North, 72 (34%) on the East, 41 (20%) on the West and 45 (21%) South elevations. The survey of the houses revealed that whether households would use balconies or not depend on some reasons. Some balconies were abandoned based on their location due to privacy issues, as there are open to neighbours. Where households have some privacy and they intend to use the balconies, some still not used because of exposure to direct sunlight especially when located on the East and West facades. The distribution of balconies on the different elevations of buildings are presented in Table **5-3** and figure 5-18.

5.4.3 House open spaces

As expected, all houses have outdoor spaces. None of the houses surveyed has 'only indoor' open space for relaxation or any other activities. This is because government policy recommended that every house must have offset from the plot on all sides. All the 72 villas have outdoor open spaces while nine have both outdoor and indoor open spaces. Households are comfortable in indoor open spaces as it affords them privacy but complained about the size, which is not adequate for sitting and other activities. Another problem with the enclosed indoor open space is that it does not allow users to connect with outdoor open spaces. Table **5-4** illustrates the distribution of indoor only, outdoor and both indoor and outdoor open spaces.

Table 5-4 different type of open spaces.

Availability of open spaces in houses	Indoor only	Outdoor	Both
	0	72	9

- **The contents of open spaces and time of use**

This section of the survey is to determine what households require for open spaces. The various contents of open spaces discovered during the survey and their corresponding percentages are presented in Figure 5-19. It shows the hierarchy in the contents of open spaces bases the survey. The most popular contents of the open spaces are sitting, play and parking areas and plants. Information about the content of open spaces was necessary to provide data that will help the researcher in the production of the framework for the design of the contemporary house. Hitherto, the facilities provided in open spaces like the swimming pool, sitting area, and play area are not effectively put to use. This is because households felt there is no proper privacy in the open spaces containing these facilities.

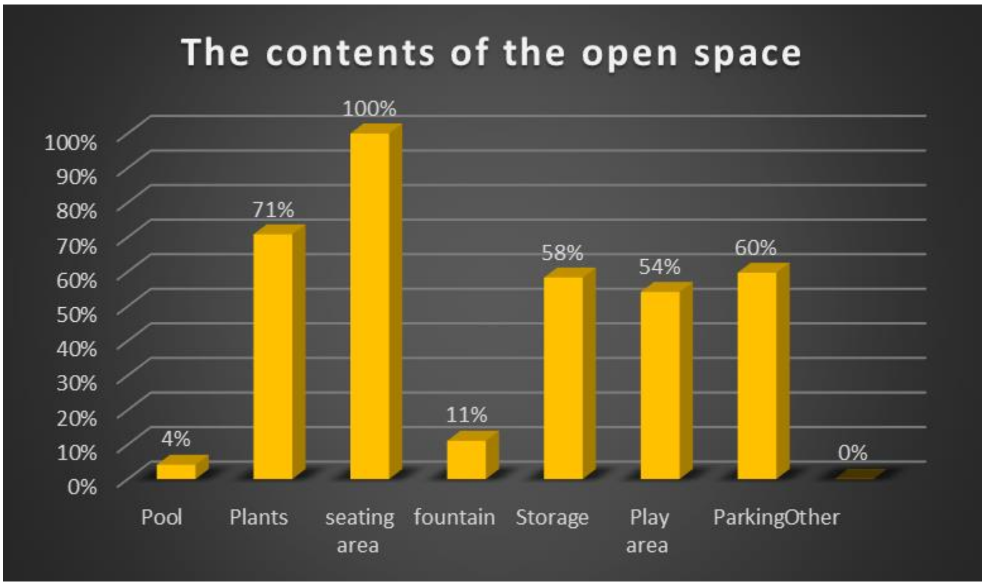


Figure 5-19 the contents of open spaces

The question of the time of use of open spaces was meant to know why households use the open spaces at the particular time of the day. The survey showed that 100% of the 72 houses used open spaces in the night. This is because it is cooler in the night in outdoor open spaces that indoors. In addition, there is adequate privacy in open spaces in the night. 40% and 60% use their open spaces in the morning and in the afternoon respectively. The 40% and 60% who use outdoor open spaces in the afternoon are majorly men because of the lack of privacy at this period of the day. None of the houses surveyed use the open spaces at noon (11 am to 4 pm). This is because it was difficult for households to stay in open spaces at this time of the day due to high solar radiation. Figure 5-19 illustrates the percentage of houses that use outdoor open spaces in the morning, noon, afternoon and night.

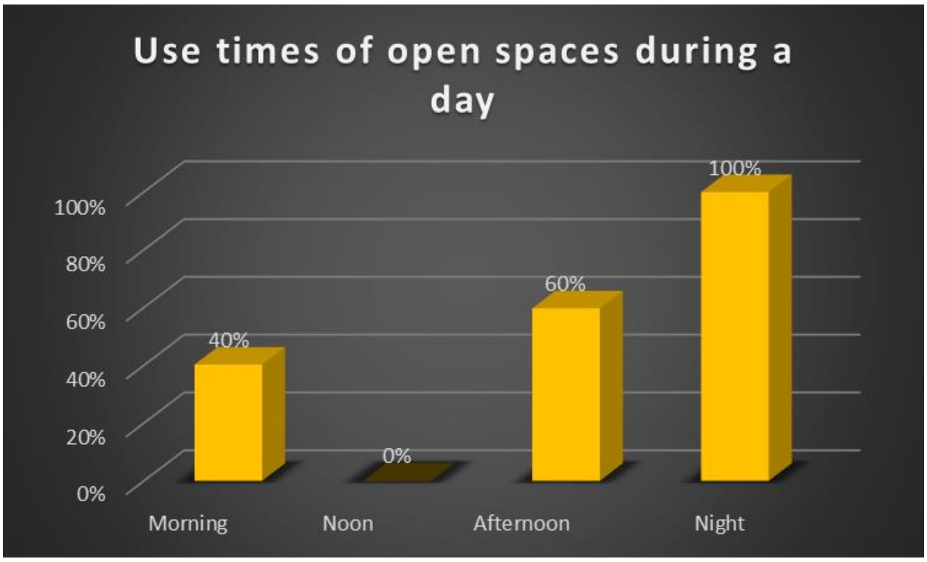


Figure 5-20 the time of use of open spaces

- **Satisfaction level of privacy between house and neighbours**

  The level of privacy between a particular house and neighbours pose a serious concern in Benghazi. Hence, there was the need to seek households view on this subject. The level of privacy will investigate the extent to which people use their outdoor open spaces. Until households are satisfied with the level of privacy, especially women they will not use the outdoor open spaces. The outcome of the survey revealed that 51% of all the houses were not satisfied at all with the level of privacy in their outdoor open spaces. 32% were slightly satisfied while 17% were moderately satisfied. None of the households was very satisfied and extremely satisfied. Figure 5-21 shows the percentage of satisfaction Level of Privacy between House and Neighbours.

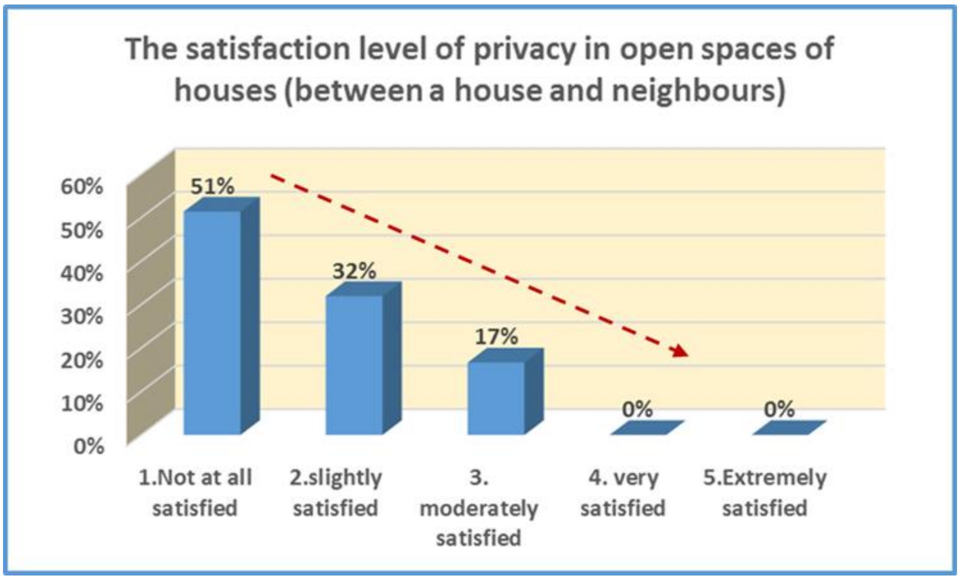


Figure 5-21 Satisfaction Level of Privacy between House and Neighbours

- **The relationship of rooms to outdoor open spaces**

Figure 5-22 illustrations the relationship between rooms and outdoor open spaces, which is determined by the number of openings in the room(s) that are linked to the outdoor open spaces. The information from this section of the questionnaire will guide the researcher in developing the framework for the design of the contemporary house. The survey revealed that on the ground floor of villas, the strongest relationship exists between the kitchen, living and the outdoor open spaces in terms of windows, doors, and verandas. Open spaces are not always connected to guest rooms with openings because of privacy issues. On the first floor, the strongest relationship exists between bedrooms and outdoor open spaces by balconies with 40%. The survey shows 26%, 23%, 30%, 20% and 2% of openings between kitchen, living, bedroom, bathroom, and guestroom respectively.

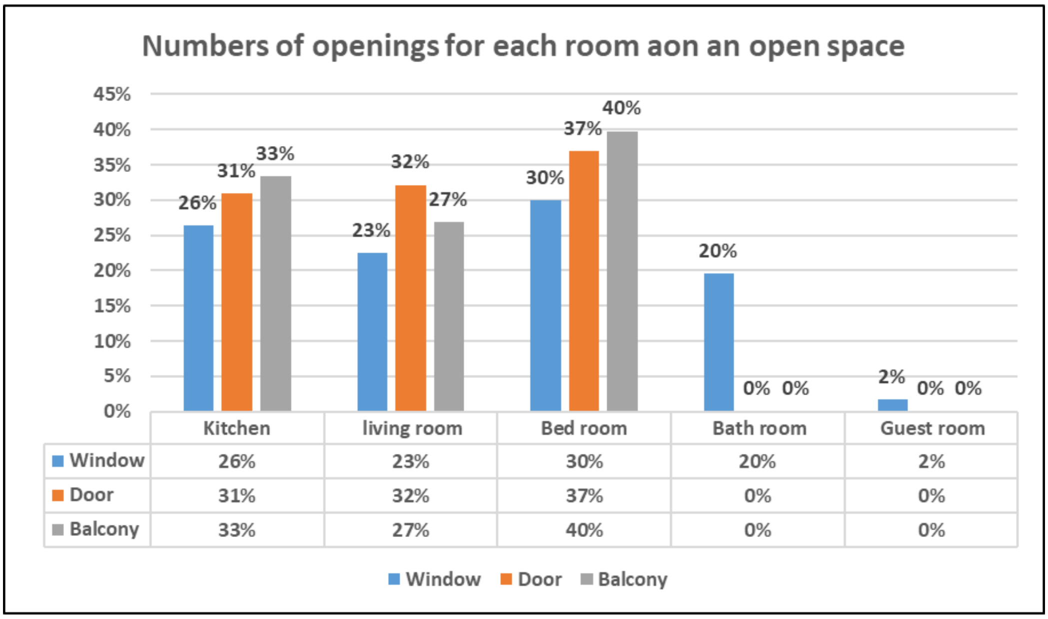


Figure 5-22 the relationship between rooms and outdoor open spaces

- **Effect of Inner open spaces on the level of privacy and thermal comfort**

This section of the survey was is intended to know whether households have knowledge on the effect of inner open spaces on the level of privacy and thermal comfort in buildings. The level of the knowledge of households in this regard with determines the ease or difficulty in encouraging the use of inner open spaces in the design of houses. All the respondents have some knowledge on the effect of inner open spaces on the level of privacy and thermal comfort in buildings.

- **Households' preference on the type of open space**

As a build-up to the previous section, the researcher asked the respondents about the type of open space they preferred. This information will feed into the framework for the design of contemporary houses. The various designs of open spaces are presented in Figure **5-23**.

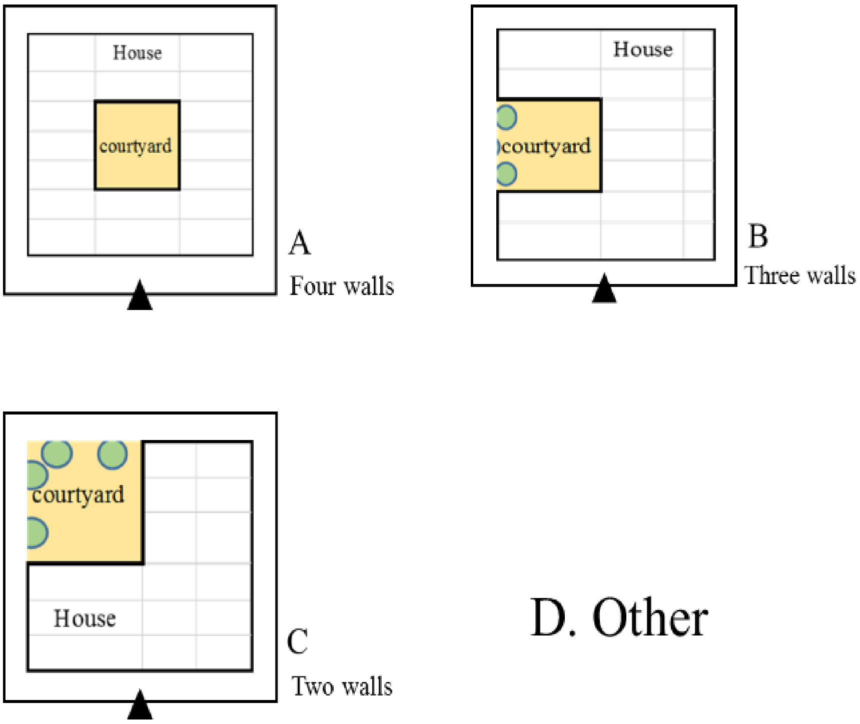


Figure 5-23 different designs of open spaces

The survey showed that 72% of the houses preferred side open space (three walls), 8% preferred inner open space (four walls), 17% went for corner open space (two walls) and 3% were in favor of other open spaces. Figure 5-24 illustrates this information.

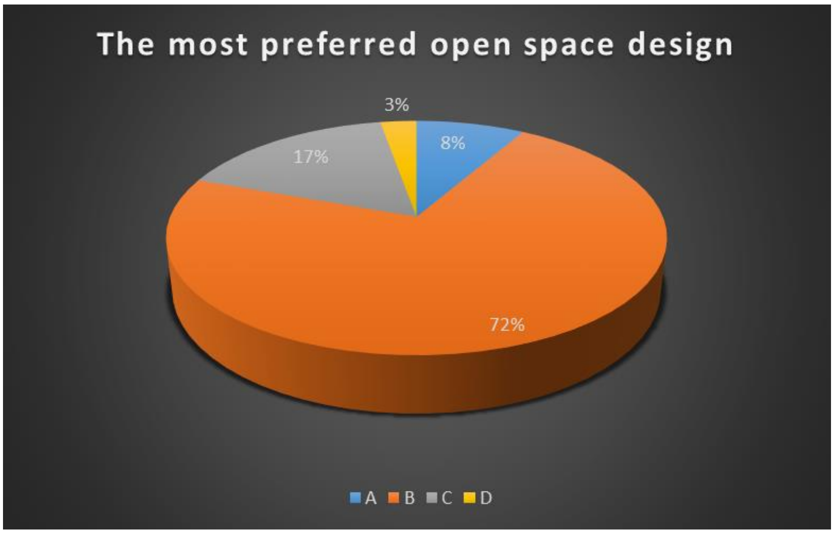


Figure 5-24 the various design of open spaces

5.4.4 Perception of thermal comfort

This section of the questionnaire was necessary to provide information on thermal perception in houses with or without the use of mechanical cooling systems. The questionnaire instrument was administered to most respondents in guest rooms. Out of the 72 houses surveyed, 50% have their ACs switched on while the other 50% have their ACs switched off during the time of the interview.

- **Type of mechanical cooling system**

Households use different mechanical cooling systems in their houses. It was discovered during the survey that all the respondents have ACs in their buildings. In addition to ACs, 13% of the total number of houses have roof fan while 29% use portable fans. Each household has an average of five ACs. This shows that all the houses rely hugely on mechanical cooling systems to achieve thermal comfort. Moreover, it is an evidence of high-energy consumption by buildings in Benghazi.

- **AC set point**

The researcher requires the average control temperature for ACs in houses. This was intended to provide information that will guide the research in conducting a dynamic thermal simulation in DesignBuilder. The ACs control set point for houses varies between 16^{0}C - 24^{0}C. The distribution of the set point for the entire houses is shown in Figure 5-25.

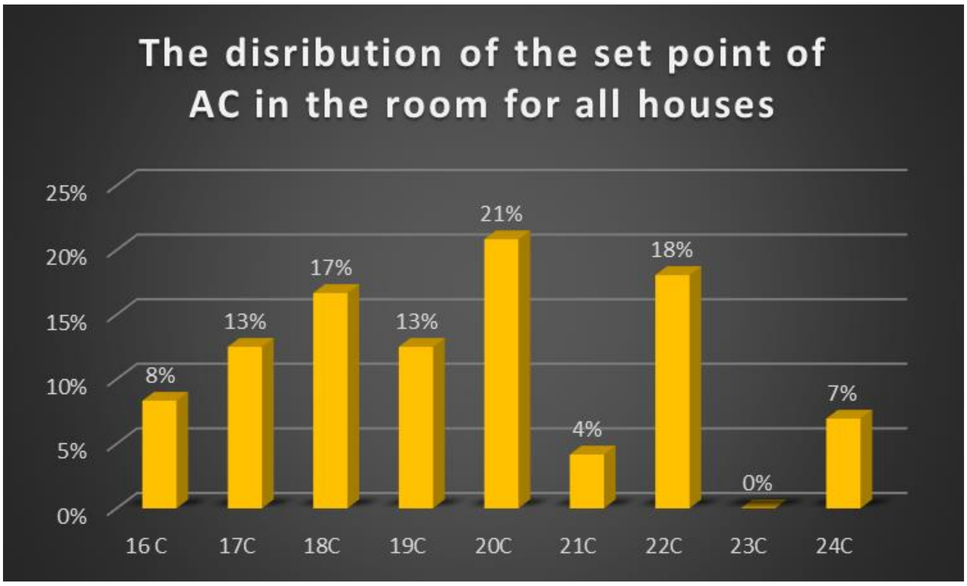


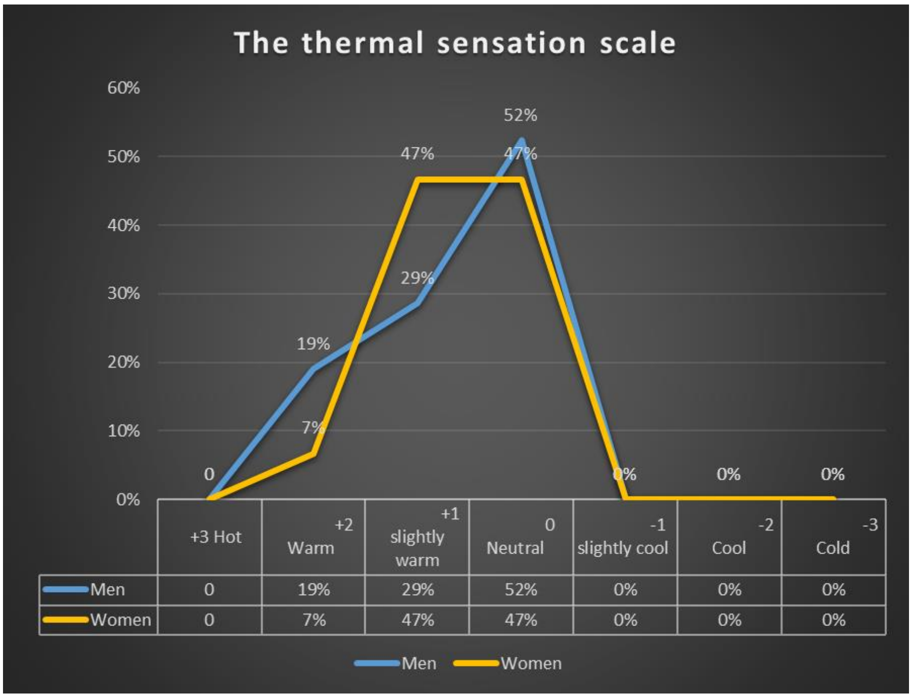
Figure 5-25 the distribution of the set point for the all houses

- **Thermal sensation scale**

As discussed in chapter 2, there are two methods of determining the acceptable thermal condition in occupied spaces. These are through Predictive Mean Vote (PMV) and Adaptive Method. To use PMV, the PMV should be near to Actual Mean Vote (AMV). An adaptive method is used when PMV does not an accurate. During the survey, the seven points' thermal sensation scale by ASHRAE was used to compare between PMV and AMV for all the respondents.

- **Actual Mean Vote (AMV)**

The AMV for men and women were determined separately based on their responses during the survey. The results revealed that for the neutral and warm levels, men thermal sensations were higher than women. On the neutral level, the percentage for men and women are 52% and 47% respectively. On the warm scale, 19% was recorded for men while 7% was for women. A higher value of 47% was recorded for women only on the slightly warm level. On this scale, men scored 29%. The Figure 5-26 shows the AMV for men and women.



	+3 Hot	+2 Warm	+1 slightly warm	0 Neutral	-1 slightly cool	-2 Cool	-3 Cold
Men	0	19%	29%	52%	0%	0%	0%
Women	0	7%	47%	47%	0%	0%	0%

Figure 5-26 the AMV for men and women

- **Predictive Mean Vote (PMV)**

The researcher measured the air temperature (dry and wet bulb temperature), airspeed, humidity, and globe temperature. The respondents' metabolic rate (met) and clothing level (clo) were determined while the mean radiant temperature (MRT) was calculated for each respondent (72 villas for indoors, open spaces and outdoors) by using the following equation (Gao, Wang & Wargocki, 2015):

$$MRT = Tg + 2.44\sqrt{V}\,(Tg - Ta)$$

Where *Tg* is Globe temperature, *V* is Air velocity and *Ta* is Dry bulb temperature

These was necessary in order to calculate thermal sensation using CBE thermal comfort tool (http://comfort.cbe.berkeley.edu/) as Figure **5-27**. Table **5-5** shows some measurements which have been done in rooms.

Table 5-5 some measurements for some houses

Room Temperature										
House label	Dry-bulb (^{o}C)	Wet-bulb (^{o}C)	Average of Air speed (m/s)	Globe Temperature (^{o}C)	Humidity (%)	Clothing level (clo)	AMV	PMV	MRT	Operative Temperature (^{o}C)
H2	24.6	18.6	0.05	25.0	56	0.57	0	0.03	25.2	24.9
H3	24.0	20.5	0.05	24.5	66	0.57	0	0.04	24.8	24.4
H4	23.9	17.4	0.05	24.5	59	0.57	0	0.01	24.8	24.4
H5	28.5	23.9	0.10	28.75	68	0.57	2	2.22	28.9	28.7
H6	25.7	17.6	0.10	26.5	44	0.57	0	0.46	27.1	26.4
H7	27.5	19.7	0.05	29.3	62	0.57	1	1.25	30.3	28.9
H8	26.3	21.3	0.15	27.9	64	0.57	1	1.1	29.4	27.9
H9	28.2	21.8	0.10	30.5	59	0.57	2	2.2	32.3	30.2
H10	24.0	16.9	0.15	25.1	50	0.57	0	0.02	26.1	25.1
H11	26.2	19.0	0.05	28.1	66	0.57	1	1.06	29.1	27.7
H43	26.5	20.7	0.05	28.1	59	0.63	1	1.07	29.0	27.7
H44	26.4	19.4	0.10	26.9	51	0.63	0	0.68	27.3	26.8
H45	27.7	23.8	0.10	28.5	72	0.63	1	1.35	29.1	28.4
H46	27.4	23.4	0.15	28.2	71	0.63	1	1.21	29.0	28.2
H47	27.2	18.2	0.05	27.5	41	0.63	0	0.82	27.7	27.4
H48	26.2	18.3	0.05	26.5	55	0.63	0	0.55	26.7	26.4
H49	24.0	15.9	0.05	24.5	56	0.63	0	0.01	24.8	24.4
H50	27.8	22.8	0.15	31.5	65	0.63	2	2.03	35.0	31.4
H51	24.0	18.1	0.05	25.1	56	0.63	0	0.13	25.7	24.9
H52	27.3	23.4	0.05	27.8	72	0.63	1	1.2	28.1	27.7

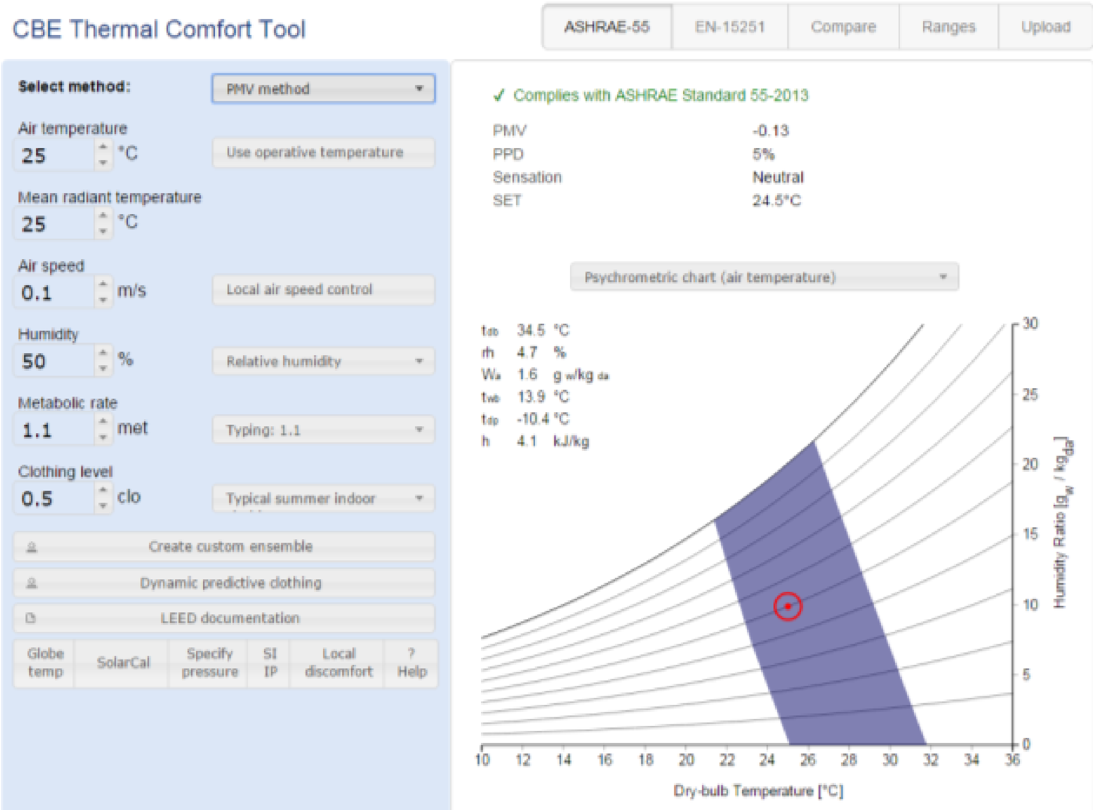


Figure 5-27 calculation of thermal sensation using CBE thermal comfort tool

Source: (http://comfort.cbe.berkeley.edu/)

- **Comparison between PMV and AMV**

There were some differences in the result of the comparison between the PMV and AMV when AC was turned on in room where the measurements had been done. Most of the results of AMV were neutral (0) while the results of PMV were slightly warm which is above (0.5) for example in houses H22, H44, H47, H48, H55, H58, H66 and H69. Hence, there is no strong agreement between PMV and AMV because PMV shows higher level than AMV and is not an accurate predictor of comfort. Thus, the researcher decided to use the adaptive method in the comfort zone using DesignBuilder. The results are presented in Figure **5-28**.

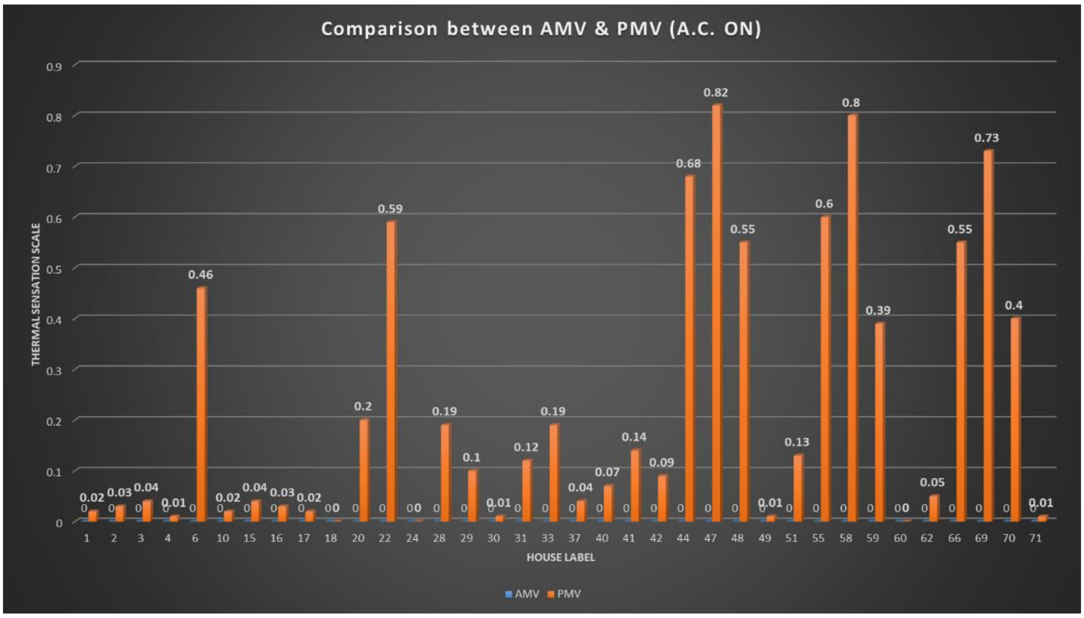


Figure 5-28 comparison between AMV and PMV

- **Adaptive Method**

As state earlier, the adaptive method of determining comfort sensation require the use of operative temperature. Hence, it was necessary to calculate the operative temperature for all residents. This was done using the dry bulb temperature and the mean radiant temperature using the equation, $To = (Td + MRT)/2$ where, To is the operative temperature, Td is the dry bulb temperature and MRT is the mean radiant temperature (Simone et al, 2007).

- **Comparison between the Operative temperature for men and women at neutral thermal scale**

The neutral level on the thermal sensation scale is when the respondents are happy with the operative temperature in their buildings. Only 22 respondents who were men fall under the neutral thermal scale. The mean operative temperature for men is 25.2^{0}C. The operative temperatures for these respondents are presented in Figure 5-29.

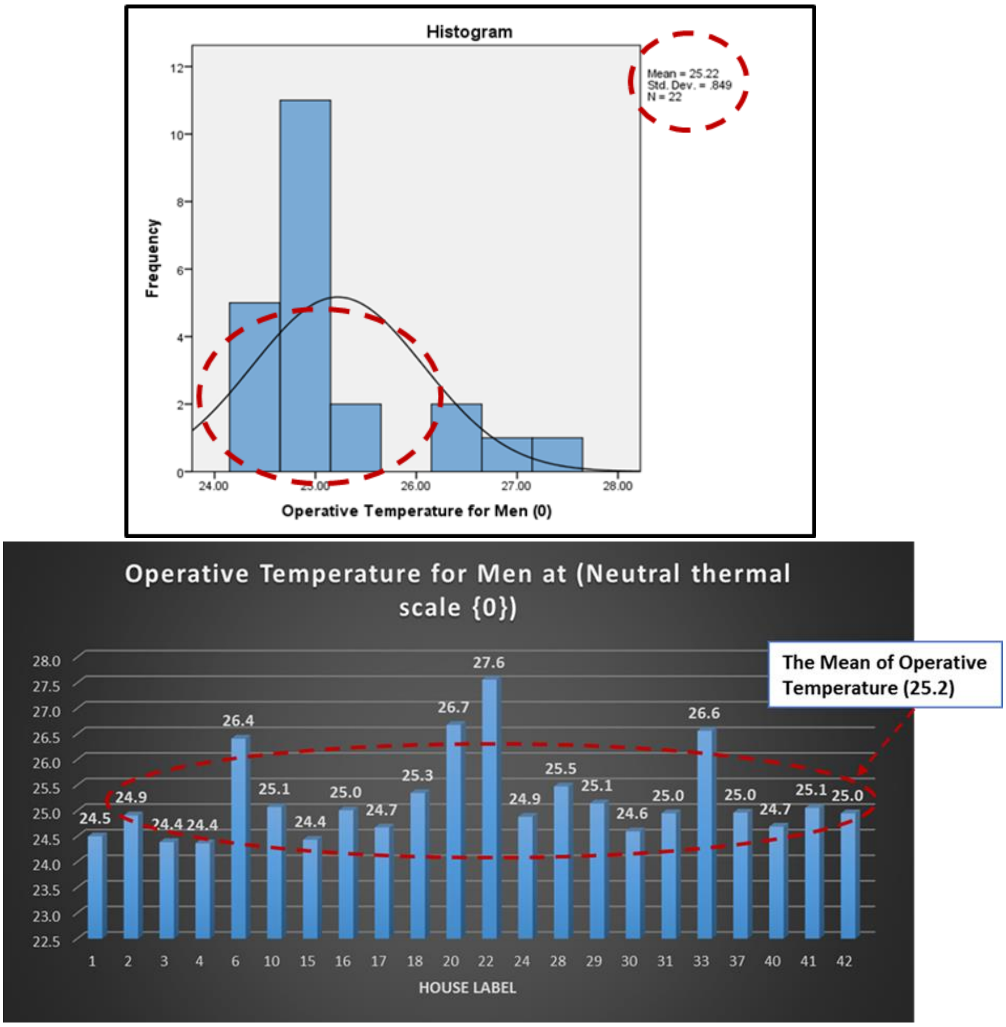


Figure 5-29 the mean operative temperature for men

For women, 14 respondents fall under the neutral thermal scale. The mean operative temperature for women is 26.0^{0}C. The operative temperatures for these respondents are presented in Figure 5-30.

During the visit, it was observed that the level of clothing for women was higher than men. For instance, the highest clothing level for women observed was 0.63 while that of men was 0.57. Despite that, women were comfortable at a higher temperature than men. This seems to confirm the idea that women feel more comfortable at a higher temperature than men (Zhai et al, 2014).

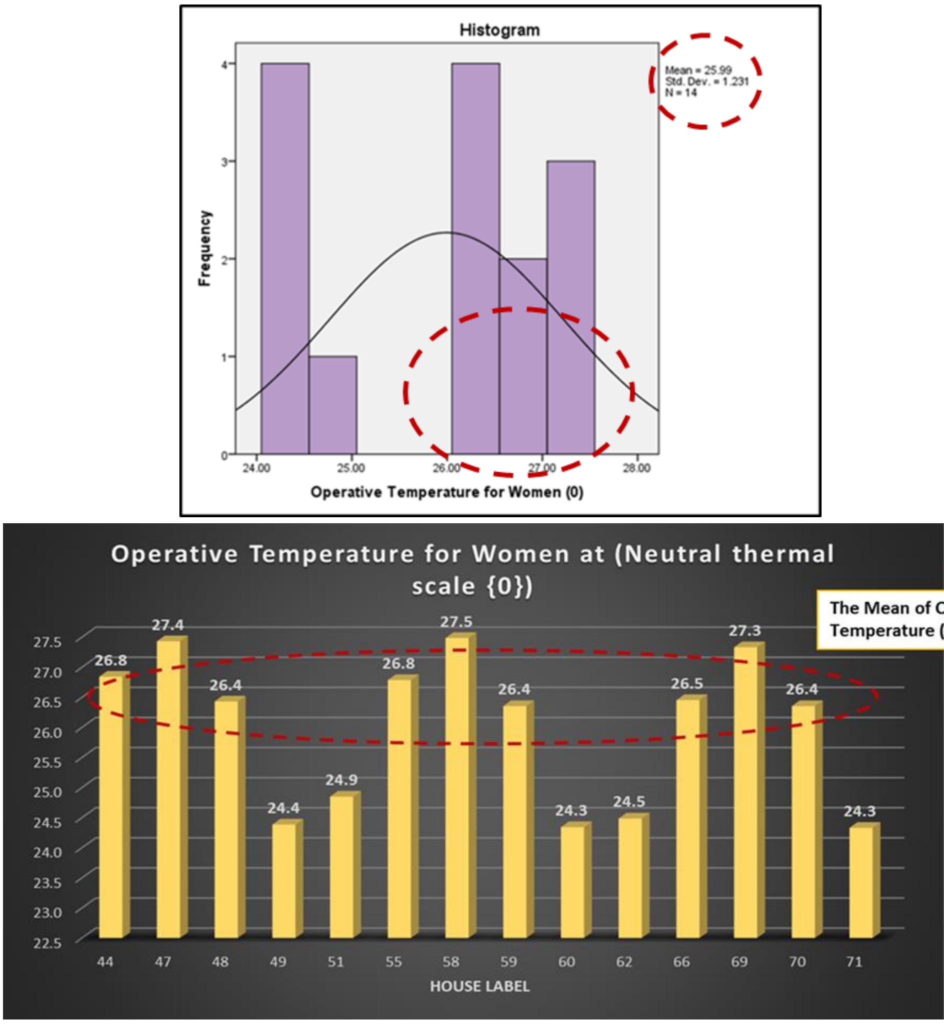


Figure 5-30 the mean operative temperature for women

- **AMV and Operative Temperature for AC on and Off**

The AMV for all respondents were measured when their ACs were switched on or off. When ACs were turned on, AMV for all residents was Neutral (0) while the average operative temperature for residents was between 24.3^{0}C and 27.6^{0}C. The Figure 5-31 shows the results for AMV and operative temperature when ACs were turned on.

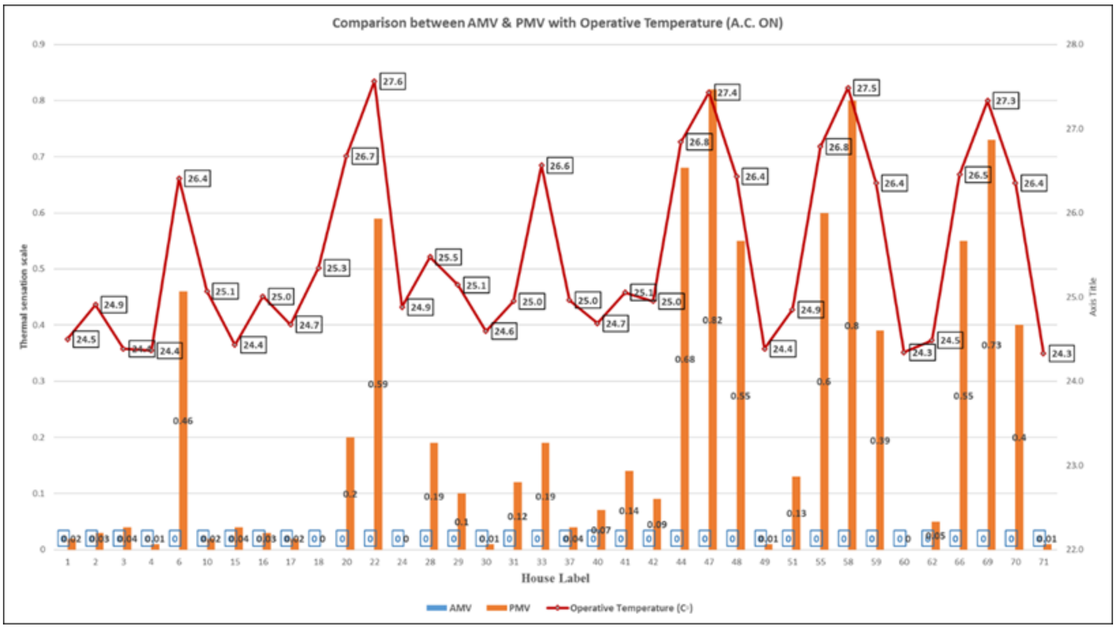


Figure 5-31 AMV and Operative Temperature for AC On

When ACs were turned off, AMV for residents was slightly warm (+1) and warm (+2) while the average operative temperature for residents was between 27.4^{0}C and 31.6^{0}C. The Figure 5-32 shows the results for AMV and operative temperature when ACs were turned off.

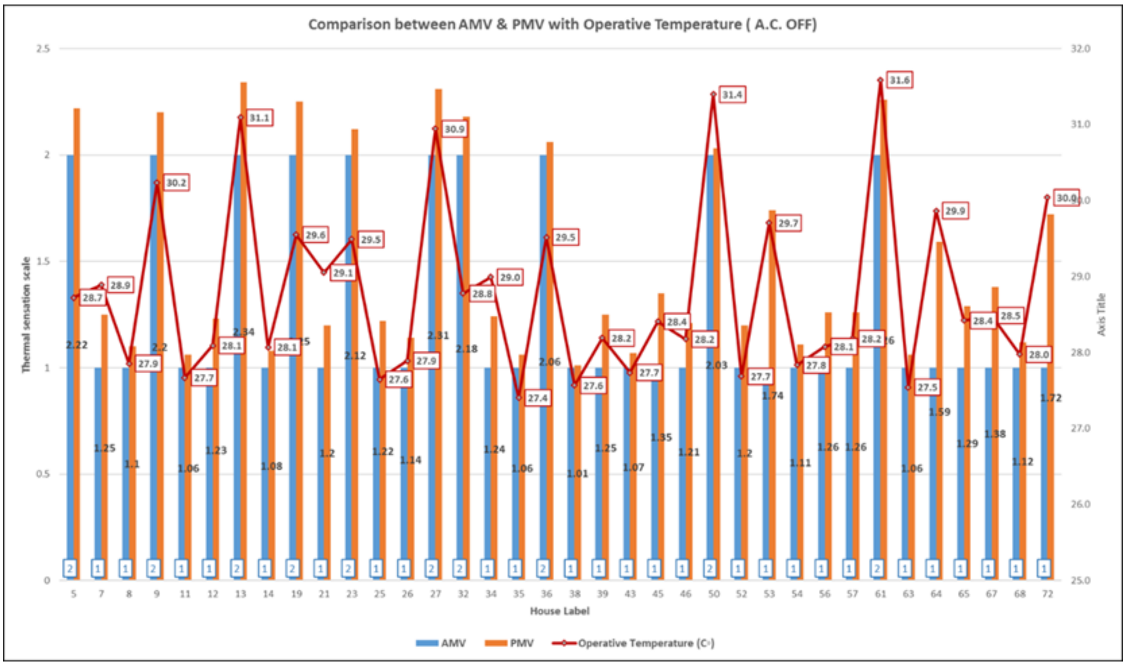


Figure 5-32 AMV and Operative Temperature for AC Off

The results for AMV when the AC as switched no revealed that the respondents were happy at a temperature up to 27.6^{0}C. On the other hand, they were not happy when the ACs were turned off at a temperature up to 27.4^{0}C. This might be because of their emotional feeling with the use of ACs. Moreover, it might be a result of their adaptive behaviour. According to previous results, the range of operative temperature where were accepted and provide the neutral sensation for people will be between 25^{0}C to 28^{0}C. This rang will be used in the simulation of a case study in chapter six.

- **Response to thermal discomfort**

The survey of houses showed four responses to thermal discomfort in buildings. These are open doors and windows, change clothes, move to another room and sit in outdoor open space. These actions take place when the ACs are not in use by houses due to blackout. The first action, which all the respond consider on this condition is to open windows and doors. If they cannot achieve comfort, the next thing is to sit in outdoor open spaces if the can achieve comfort at such time of the day. Where sitting in outdoor open spaces is not an option due to privacy and other factors, households will move to other rooms. Another action, which is considered the least from the survey results, is to change clothes. The survey revealed that 100% will open their doors and windows for ventilation while 96% responded they sit in outdoor open spaces. The third option, which 78% went for, was to move to another room while 13% maintained that they would change their clothing in order to improve their comfort condition as in Figure 5-33. This result shows that it is difficult for people to be comfortable in their houses without mechanical ventilation. This may be as a result building design, which does not consider proper orientation, ventilation, and outdoor open space.

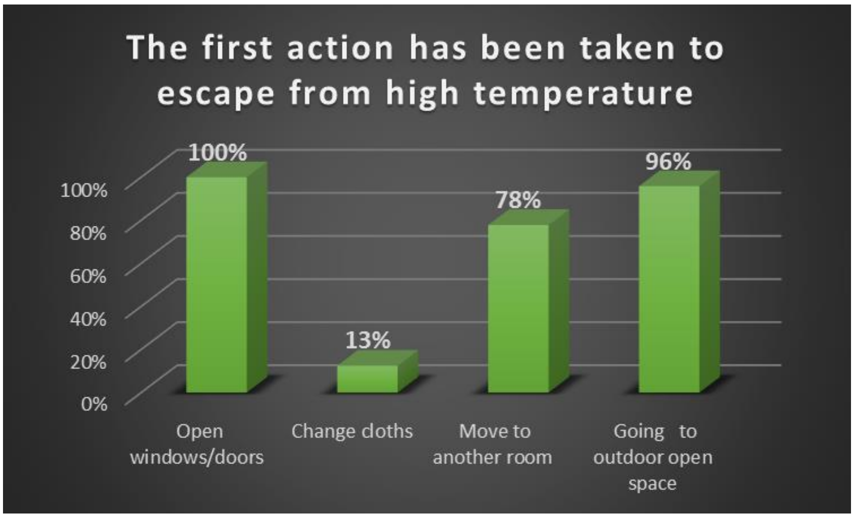


Figure 5-33 Response to thermal discomfort

- **Perception of comfort during questionnaire administration and comfort expectation**.

During the visit to households, respondents were asked to state their comfort perception and expectation. Out of the 72 respondents, 30 women and 42 men responded to these questions. For the 30 women, 18 representing 60% voted for no change while 12 representing 40% wanted to be cooler. On the other hand, out of the 42 men, 20 representing 48% were happy with their comfort level while 22 representing 52% wanted to be cooler. This confirms the previous result that the level of thermal discomfort with men is higher than that of women. Figure 5-34 shows the thermal comfort perception and expectation for women and men.

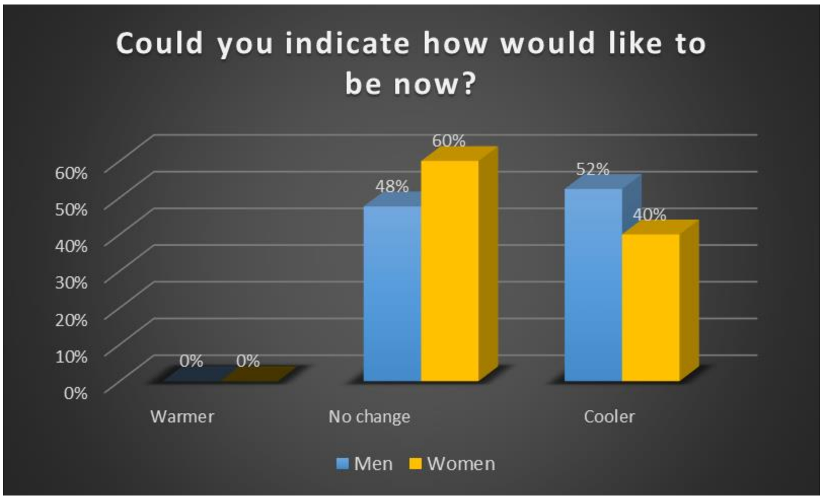


Figure 5-34 the thermal comfort perception and expectation for women and men

5.4.5 Energy Consumption and Human Behaviour

This section of the questionnaire deals with questions relating to the number and capacity of ACs in houses, season and time of use per day and the average monthly electricity bill. The households' responses are documented in the next sections.

- **Location, Percentage, and Capacity of ACs in Houses**

All the 72 respondents visited have ACs in their houses. These ACs are located in the bedroom, guest room, living, and kitchen. All the houses have ACs in their guest room. This might be because of the priority they give to their guest in terms of comfort. Approximately 92% of the houses have ACs located in their living rooms while 84% of the ACs in houses are located in the kitchen. The reason for this is that family members spend most of their time in the living room and the kitchen. Only 64% of the ACs in the 72 houses are located in the bedroom. Most of these ACs are located in adult bedrooms as some parents felt it is ideal to put ACs in the children's bedroom. This might be the reason why the least percentage of ACs are located in bedrooms. Figure 5-35 illustrations the numbers of A.C. units in different rooms in a house.

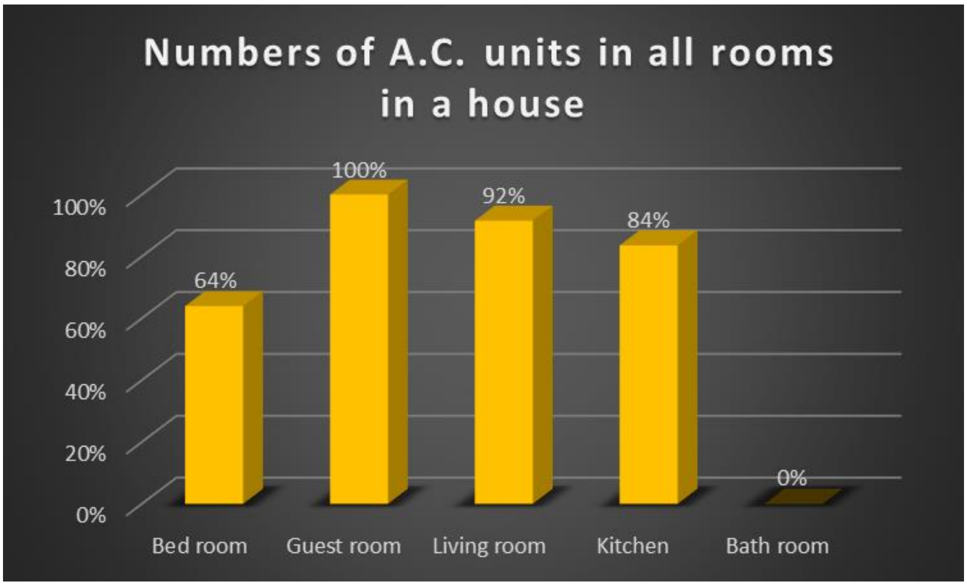


Figure 5-35 numbers of A.C. units in different rooms in all houses

The capacity of ACs in houses ranges from 9,000 – 30,000 BTU. All houses have 24,000 BTU capacity ACs that are usually located in living rooms and kitchen. The higher capacity of ACs ranging from 24,000 to 18,000 BTU is located in guest rooms. This is because guest rooms are usually larger in size compared to other rooms. The least capacity of ACs which ranges from 9,000 to 18,000 BTU are located in bedrooms as higher capacities can make the bedrooms extremely cold for the users. Figure 5-36 illustrates the ACs capacities and the percentage representing the number of users in houses.

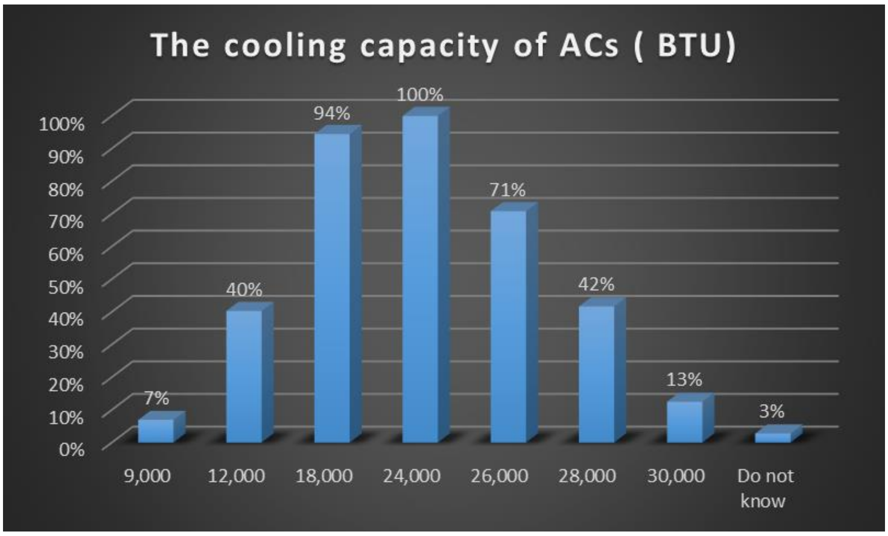


Figure 5-36 the ACs capacities

- **Season and Time of AC Use per day**

The questionnaire revealed that all the houses use ACs during summer. This supports the need to focus attention on energy use and thermal comfort in houses during the summer period.

In addition to this, some houses use ACs in winter, autumn, and spring. In autumn, 32% use ACs in their houses because the weather is still hot at this time of the year since the following summer period. In addition, in Spring, 47% use ACs because the temperature starts rising especially in April and May.

In winter months, 11% of the houses use ACs. This is because people use ACs for only a few days during this period when they are not comfortable in their houses. Figure 5-37 presents the percentage use of ACs per year for all houses.

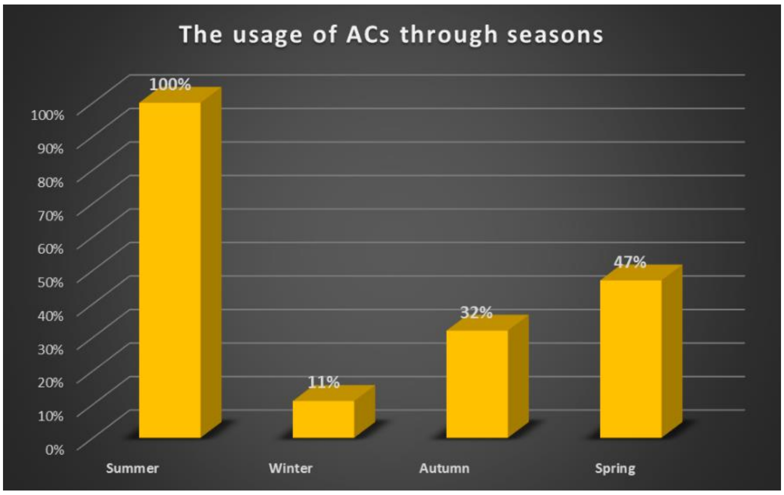


Figure 5-37 using ACs through a year

The survey revealed that 80.5% of all the houses use ACs for 24 hours per day. The result shows that only a few people use ACs in the morning between 6 a.m. and 12 noon. This represents 2.8% of the total number of householders. This is because at this time of the day people embark on housing cleaning. Hence, they prefer to open windows for the exchange of air between outdoor and indoor. As temperature start to rise during the day, more houses switch on their ACs between 12 noon to 12 midnight. Figure 5-38 shows the time of the use of ACs during summer per day.

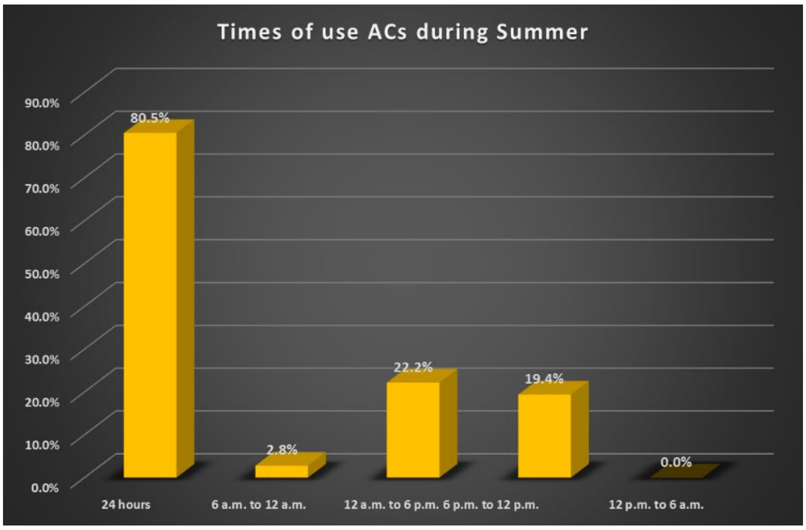


Figure 5-38 the time of use of ACs during summer per day

5.4.6 Lighting

All houses in Benghazi depend on electricity supply from the national grid referred to as 'Libyan Electricity Company' for artificial lighting, mechanical cooling and any other electrical requirements by houses. All the houses survey use incandescent bulbs for lighting in their houses. Some houses use a combination of incandescent, fluorescent and Low Emission Diode (LED) bulbs. For houses in this category, the majority of bulbs used were incandescent bulbs. It was observed that house owners did not consider the size of rooms before deciding on the number and capacity of bulbs. For instance, the researcher discovered that the number of bulbs that were used in some houses was more than it is required, especially in living and guest rooms. The common size of the guest room is between 30m^2 to 35m^2. Some houses visited used an average of 10 incandescent bulbs of 40watts capacity each. This confirms the high use of energy in houses because of users' behaviour.

5.4.7 Average Monthly Electricity Bill

Energy bills are relevant to this research as it determines the rate of energy consumption in buildings and the amount householders spend on energy monthly or annually. Hence, the questionnaire included a question on this subject. The minimum energy bills from the results of the survey were 100 LYD while the maximum was 350 LYD. The average energy bills for the 72 houses was 150.5 LYD. A study has revealed that electricity bills in Libya per kW/h is 0.031 LYD (GECOL, 2012). Based on this data and the average electricity bills, the researcher calculated the electricity bills per kW/h as 150.5/0.031 = 4854.8 LYD is the amount of energy consumed in a month. Hence, the total annual energy consumption per house is 58258.06 kWh.

5.4.8 Comparison between MRT for (Indoor, Outdoor open space, Outdoor)

There was the need to calculate the mean radiant temperature (MRT) for an indoor, outdoor open space and outdoor. This will help the research to know the difference between the various spaces. Hence, during the survey, the researcher measured the dry-bulb, wet-bulb and globe temperatures, humidity, and velocity for indoor, outdoor open space and outdoor to calculate their MRTs.

The results show that there is a significant difference in terms of MRT between indoor and the outdoor open space and outdoor. The difference in MRT between indoor and outdoor is approximately 6.8^{0}C while the difference in MRT between indoor and outdoor open space is 5.2^{0}C. The difference between the outdoor and outdoor open space is minimal at 1.6^{0}C. The lowest and the highest indoor temperature measured was 24.5^{0}C and 32.5^{0}C respectively. Figure **5-39** shows the space layout, Figure 5-40 illustrates the MRTs in indoor spaces, open spaces and outdoor spaces for all houses while Table 5-6 show some measurements in some open spaces and outdoors.

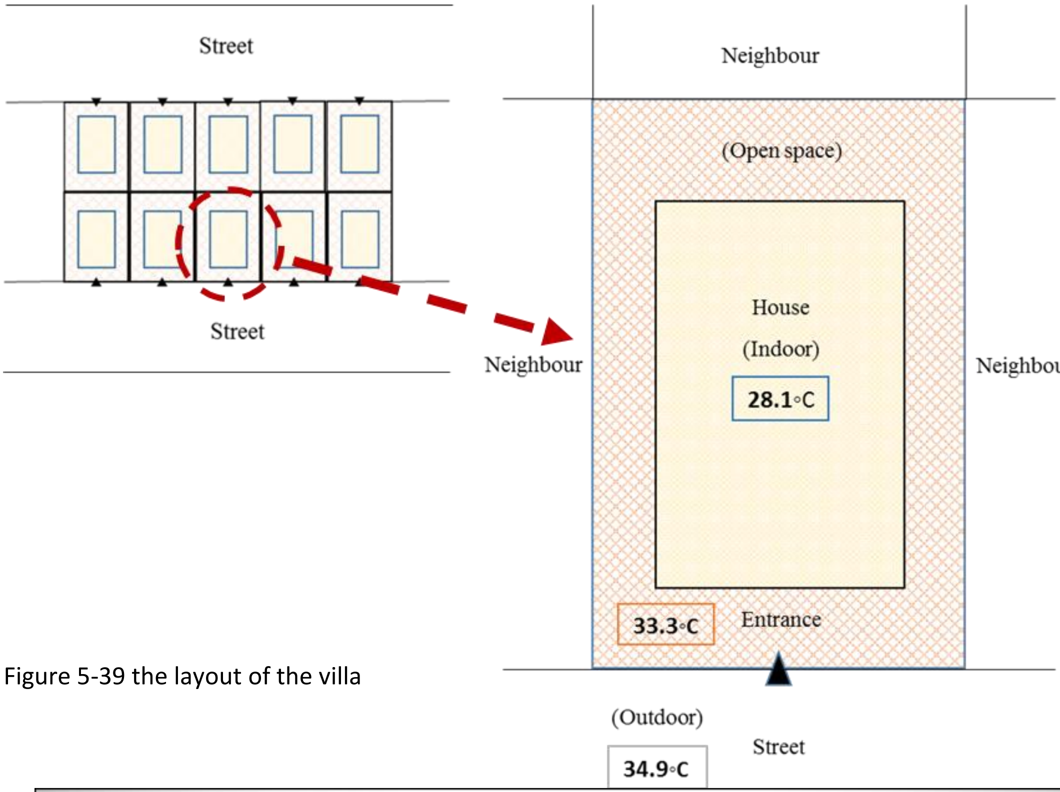


Figure 5-39 the layout of the villa

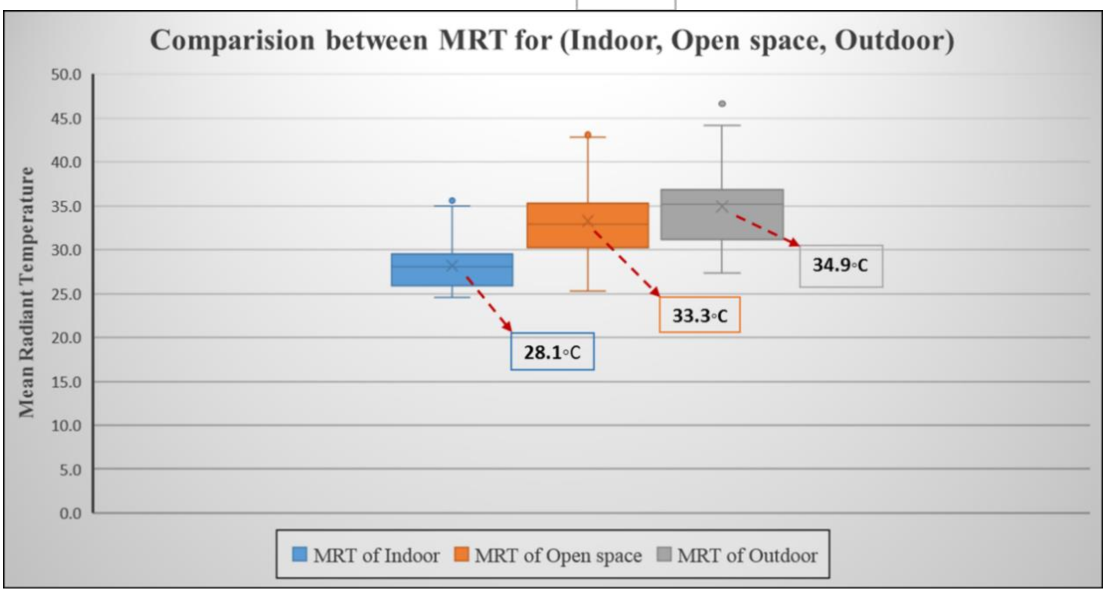


Figure 5-40 MRT of indoor, open space and outdoor

Table 5-6 some measurements in some open spaces (garden) of villas

Open Space Temperature						
House label	Dry-bulb (Co)	Wet-bulb (Co)	Air speed (m/s)	Globe Temperature (Co)	Humidity (%)	MRT
H1	36.5	29.8	0.85	36.9	61	37.8
H2	28.25	21.7	1.8	28.5	56	29.3
H3	28.9	25.2	0.7	28.9	74	28.9
H4	28.2	24.0	1.0	28.2	70	28.2
H5	32.3	25.2	0.7	33.9	56	37.2
H6	28.0	21.2	0.85	29.5	54	32.9
H7	28.7	24.7	0.75	30.5	72	34.3
H8	29.8	25.1	1.0	33.0	68	40.8
H9	27.1	21.2	0.95	28.9	59	33.2
H10	27.7	21.9	1.05	29.1	60	32.6
H43	27.5	22.8	0.95	29.4	66	33.9
H44	28.4	21.8	0.85	29.5	56	32.0
H45	29.0	24.6	0.75	30.5	70	33.7
H46	27.5	23.6	0.85	28.7	71	31.4
H47	26.0	22.0	1.05	27.2	70	30.2
H48	38.5	20.8	0.7	40	18	43.1
H49	26.7	22.6	0.95	27.8	70	30.4
H50	28.7	23.9	0.9	31.5	67	38.0
H51	26.0	22.5	0.95	27.0	74	29.4
H52	27.4	24.1	0.95	27.9	76	29.1

Table 5-7 some measurements in some outdoor spaces (street) of villas

Outdoor Temperature						
House label	Dry-bulb (Co)	Wet-bulb (Co)	Air speed (m/s)	Globe Temperature (Co)	Humidity (%)	MRT
H1	36.8	30.8	1.3	37.1	65	37.9
H2	28.5	25	2.15	28.9	75	30.3
H3	29.95	25.2	1.3	30	68	30.1
H4	29.2	25	1.9	29.2	71	29.2
H5	35.5	28.5	1.15	36.8	59	40.2
H6	30.1	23.1	1.3	31.9	55	36.9
H7	30.1	25.8	1.35	32	71	37.4
H8	29.9	24.5	1.15	33.1	64	41.5
H9	28.9	24.9	3.3	30.5	72	37.6
H10	28.1	23.4	1.65	29.9	67	35.5
H43	28.5	24.1	1.45	30.5	69	36.4
H44	28.9	23.3	1.3	30.5	62	35.0
H45	30.5	26.7	1.25	31.5	74	34.2
H46	26.6	23.1	1.7	28.1	74	32.9
H47	26.2	22.1	1.55	27.1	70	29.8
H48	38.7	20.9	1.15	40.2	18	44.1
H49	27.3	24.0	1.85	28	76	30.3
H50	29.1	24.6	1.25	30.9	69	35.8
H51	27.2	23.9	1.4	29.1	76	34.6
H52	27.9	24.7	1.3	28.7	77	30.9

5.4.9 Summary of the Main Findings from the Householders' Survey

The survey of the 72 houses revealed relevant data for the progress of this research. This data, which deals with householder's views about the design of houses, privacy, and thermal comfort and energy consumption in buildings, are summarised under the following headings.

- **House design**

Civil engineers designed the majority of the houses. This might be the reason why most of the houses visited lack basic architectural principles. For example, lack of proper orientation, inappropriate size, and location of openings. Another challenge with the design of houses is about the provision of balconies. While the majority of the houses visited do not use their balconies, others converted their balconies to indoor spaces. Furthermore, there were problems regarding privacy with the design of open spaces. Most open spaces were abandoned because householders felt there were not satisfied with the level of privacy between them and their neighbours. Thus, it is strongly recommended based on the survey that architects should be made to design houses and not civil engineers or other non-professionals.

- **Privacy Dimension**

The result of the survey shows that issues related to privacy are a strong challenge in the design of houses. The most difficult aspect of privacy is between householders' and their neighbours. Hence, outdoor open spaces may not be put to use until privacy challenges are resolved.

- **Thermal comfort Dimension**

Houses depended solely on mechanical cooling systems for thermal comfort, especially when there is a supply of electricity from the national grid. During the blackout, most householders prefer to go outside into the outdoor open spaces to relax and receive fresh air. This emphasizes the need for proper outdoor open spaces for the householders. It was difficult for householders to stay indoor during the blackout as they rarely achieve desire comfort due to poor design. Earlier in section 5.4.4, it discussed that there was no an agreement between PMV and AMV for both women and men and as such PMV method comfort sensation in DesignBuilder. Instead, the adaptive method will be used to conduct a dynamic thermal simulation in DesignBuilder.

- **Energy consumption Dimension**

There is high-energy consumption by houses caused mainly by the use of ACs. As discussed earlier, it was revealed during the survey that all the respondents use ACs in their houses. Majority of the householders use ACs for whole 24 hours in a day during the summer period. The higher capacity of ACs (BTU), more than necessary were extensively used in houses, especially in the guest and living rooms leading to high-energy consumption. In addition to the use of ACs, 13% of the total number of houses have roof fan while 29% use portable fans. Further, people depended so much on artificial lighting using incandescent bulbs, which consumes a lot of energy.

5.5 Interview with Professionals

This section documents the analysis of the semi-structured interview conducted with twelve professionals in Benghazi. Nine of the professionals were architects while three were civil engineers. As discussed earlier, civil engineers were included in the interview because of their influence on the design of houses in Benghazi. The interview with professions aims to seek their opinions on the design of houses in terms of social aspect and climate for Benghazi, Libya.

The interviews were conducted in the month of August 2016. The interview comprised of eight questions and each interview lasted for about 10 to 15 minutes. All the interviews were recorded using a recording device. In addition to audio recording, some respondents were videotaped. The Arabic language was used to conduct all the interviews and the researcher later translated to the English language.

- **Professional Background**

All the professionals interviewed have different backgrounds. These include academia, housing sector, and private practice and government agencies. The respondents comprised of seven males and five females with a minimum of 15 years practice experience. They were all above 40 years of age with postgraduate qualifications. All the interviewees were a label with the acronym IP1, IP2, IP3 … IP12 for identification. Respondents labelled IP10, IP11 and ip12 are civil engineers.

5.5.1 Professionals' Opinions on the Achievement of Sustainable Houses through Social and Climatic Design

All the interviewees agreed that sustainable houses could be achieved through social and climatic design. One of the respondents added that it could be achieved through socio-cultural values and adaptation to local climatic conditions (IP3). Another interviewee agreed with this position by stressing that 'it can be achieved by social and climatic design, sustainable design'. Some respondents agreed that it can be realized but will require planning, funding, public-private partnership (PPP) and private funding initiative (PFI).

5.5.2 Professionals' Opinions on the Effect of Western Architecture on Libyan Modern Architecture

All the interviewees agreed that western architecture has effects on Libyan architecture. Some argued that it has both negative and positive effects on the development of Libyan architecture. The negative influence according to some respondents was that the western architecture did not take into consideration social, cultural and climatic factors. Moreover, modern architectural elements like large glazing units on building facades are alien to the climate. Only one of the respondents agreed that western architecture had a positive influence on Libyan modern architecture. This he argued was about the advanced method of construction (IP12). According to a respondent, Libyan modern architecture was majorly influenced by Italian architecture. This might be due to the influence on Italy on Libya during the colonial period.

5.5.3 Professional Opinions on the Influence of Contemporary Housing in Terms Of Appropriateness to Provide Privacy between Family and Neighbours

Architects and civil engineers responded differently to this question during the interview. While architects were of the opinion that there was no privacy in contemporary buildings between family and neighbours, civil engineers have contrary views. Architects emphasize the need to design buildings with an improved level of privacy for families, which now does not exist in contemporary housing. Their opinions were based on the experiences they had working in the private sector in Benghazi. An architect related his interaction with a client who suggested that they should design higher fences and position balconies and verandas away from the views of neighbours (IP3).

5.5.4 Professional Opinions on the Influence of Contemporary Housing in Terms of Appropriateness to Provide Thermal Comfort for Family without Using Air Conditions

All the respondents were of the opinion that contemporary housing cannot provide thermal comfort for householders without mechanical cooling systems. Other comments by both architects and civil engineers on this point were on how to improve thermal comfort in dwellings based on their experiences. Civil engineers placed more emphasis on construction materials as means of achieving thermal comfort in dwellings. Some of the materials mentioned include masonry blocks, concrete blocks and reinforced concrete. A respondent suggested the use of cavity walls and thermal insulations (IP10). A civil engineer suggested the construction of high ceilings to reduce heat in dwellings as hot air rises to the top of buildings. Architects, on the other hand, suggested design strategies to reduce the use of mechanical cooling systems. Areas of consideration include orientation, courtyard, thick walls and using white colour on the external walls and roof. Some architects suggested the use of local building materials in buildings to improve thermal comfort but were not sure of their durability, stability, aesthetics and other factors. Civil engineers were of the views to stick to modern construction materials like concrete elements with modifications such as cavity walls and insulation to improve comfort.

5.5.5 Opinions on whether traditional houses are more environmentally friendly than contemporary houses

All the interviewees agreed that traditional houses are more environmentally friendly than contemporary houses. According to a respondent, the reason for this is that traditional architecture has local identity and characteristics and a reflection of the local environment (IP10). Traditional architecture is more environmentally friendly because of some features like a courtyard, good landscaping using plants, shading, orientation, natural ventilation, and building colours. Another reason given by some respondents was that traditional houses were designed by local practitioners who understand the climate, comfort and social needs of the people. The architects believe that contemporary houses can be environmentally friendly if they are designed by architects.

5.5.6 Opinions on what can enhance the level of privacy in traditional dwellings

All the people interviewed suggested that appropriate courtyard design could improve privacy in dwellings. A respondent specifically mentioned inner courtyard as the most important feature of the traditional architecture, which can help to achieve and maintain standard privacy in houses. The respondent added that it is important to incorporate inner courtyard in contemporary buildings. All other respondents supported this view. IP8 was of the opinion that 'traditional houses had many elements which could provide privacy as a transitional point from outside to inside direct; organisation of the house around inner spaces to provide private space for activities of families. IP4 suggested that houses should be built around a square of green and garden for privacy and intimacy among close neighbours. The respondent added that this would enhance 'a sense of family, belonging and community spirit'.

5.5.7 Opinions on climatic elements in traditional house design

Interviewees identified some climatic elements in traditional houses. The most popular among these elements is the courtyard. Others include building orientation, shading, thick wall for high thermal mass, compact open planning for houses and use of white colour paint on external walls to minimise heat gain. An interviewee argued that using these climatic elements would reduce the time of use and the number of ACs units and energy consumption in houses.

5.5.8 Opinions on borrowing elements from traditional architecture such as courtyard, openings, and orientation to improve future housing projects in terms of privacy and thermal comfort

All the respondents agreed that it is important to adopt some elements of local vernacular architecture to enhance privacy and thermal comfort in future housing developments. In addition to courtyards, openings, and orientation, civil engineers suggested the use of cavity walls as a means of improving thermal comfort. Architects are of the view that before adopting any design elements in local vernacular architecture it might be necessary to seek householders' opinion to understand their current needs as these changes due to change of lifestyle and economic status. For instance, some architects in past have changed balconies to interior spaces as householders' no longer need them. However, the adoption of the elements of local vernacular architecture cannot be achieved without some issues. Some of these are:

- There is the need for the Libyan government to provide a layout (master plan) for these types of dwellings and monitor development to suite the purpose so that it does not become a slum.
- There is an urgent need to update the existing building regulations to include this type of dwellings. This will be a relevant source of information for designers.
- The design of buildings should be the responsibility of relevant design professionals only.
- Lack of control and follow-up
- Lack of skilled manpower for this type of construction
- There is a need to improve the on the traditional building materials and the design approach.

5.5.9 Summary of Findings from Interview with Professionals

The findings from the interviews with architects and civil engineers in the Benghazi revealed relevant information regarding this research. These are summarised below:

- It was agreed that sustainable houses could be achieved through social and climatic design principles.
- Western architecture has both positive and negative effect on Libyan architecture. The negative impact is majorly in terms of lack of consideration of climatic conditions, social-cultural factors.
- Contemporary dwellings do not provide adequate privacy between family and neighbours. This is very important, as some householders have abandoned certain aspects of contemporary buildings on the ground of lack of proper privacy.
- The contemporary housing cannot provide adequate thermal comfort for householders without the use of mechanical cooling systems.
- Respondents agreed that traditional houses are more environmentally friendly than contemporary houses. One of the reasons pointed out was that traditional houses were design based on the local climate.

- To improve privacy, there is the need to design houses around an appropriate courtyard.
- Interviewees agreed that it is important to adopt some elements of local vernacular architecture and traditional house to enhance privacy and thermal comfort in future housing developments.
- The approach to the design of houses by architects and civil engineers differ. While architects lay emphasis on design principles, civil engineers lack information on how to design houses using some basic design principle like orientation and adequate privacy.

5.6 Chapter summary

This chapter presented the analysis of the research data from the study context, which involves an observational survey of existing buildings, a questionnaire survey of householders and interviews with professionals. The data collection aimed at confirming the challenges with existing contemporary buildings in terms of comfort and energy demand with particular reference to socio-cultural factors. In addition to measurements and observational survey of existing residential buildings, 72 responses were received from householders through questionnaire survey while 12 professionals were interview for their opinions on the design of houses in Benghazi.

The analysis of the survey data showed that the design of houses has little consideration for socio-cultural factors which have strong links with the means of achieving comfort in the study context. Hence, the building uses depended hugely on mechanical cooling systems to achieve thermal comfort in buildings leading to high energy consumption. The need for sitting in a shaded area with adequate privacy for relaxation and comfort was not considered in the design of the houses. Buildings that have spaces for relaxation and comfort lack adequate privacy as such spaces were exposed to neighbours. Hence, such outdoor spaces were not put to proper use while others were completely abandoned. Open plan arrangement of functional spaces was adopted for the design of some houses. This approach had a significant effect on energy consumption in buildings because ACs must work continuously for several hours to provide cooling in connected spaces. Another challenge observed was that although large windows were provided for most residential buildings, the use of thick drapes hinders natural lighting in indoor spaces leading to excessive use of artificial lighting even during the day.

The courtyard is a strong element in the design of houses in the study context. The analysis of the survey data showed that majority of the respondents preferred side courtyard to other courtyard types. All the houses surveyed depended hugely on mechanical cooling systems. Electrical fans of different types were used in houses to achieve thermal comfort. All the houses surveyed have an average of five ACs each and AC set point for houses ranges from 16^0C to 24^0C. The survey confirmed that householders cannot be comfortable indoors with using electrical cooling devices.

During the survey of houses, the seven-point thermal sensation scale by ASHRAE was used to compare between PMV and AMV for all the respondents. There was slightly difference in the result of the comparison between the PMV and AMV when AC was turned on in room when the responds for thermal sensation scale were neutral (0). For Predictive and Actual Mean Vote (PMV), the air temperature (dry and wet bulb temperature), airspeed, humidity, and globe temperature were measured appropriate instruments while the respondents' metabolic rate (met) and clothing level (clo) were determined. The Actual Mean Vote (AMV) for men and women were determined separately based on their responses during the survey. The results revealed that for the neutral and warm levels, men thermal sensations were higher than women. In addition, Women were comfortable at a higher operative temperature than men. Despite the clothing level (clo) for women was higher than the clothing level for men, women were happy at 26.0^0C which is the mean operative temperature while men were happy at 25.2^0C. Moreover, the mean radiant temperature (MRT) for each respondent was calculated by using the Fowling equation. The analysis of the PMV and AMV data showed no agreement. Thus, the researcher decided to use the adaptive method to determine the comfort zone. The results from the analysis of AMV and operative temperature for both AC on and AC off revealed that operative temperature for residents was between 25^0C and 28^0C.

On building occupants' behaviour in terms of response to thermal discomfort, householders responded in different ways. This ranges from opening windows, changing other clothes, moving from one room to another, sitting in outdoor open space and the use of fans and ACs.

The questionnaire survey showed that ACs were used in houses all the time during summer months. Of the 72 houses surveyed, 47% and 32% use ACs in Spring and autumn respectively.

Majority of houses in Benghazi use only incandescent artificial lightning. Some houses use the combination of incandescent, fluorescent and LED bulbs. Almost all the houses depended extensively on artificial lighting as windows are always closed or covered with dark drapes to enhance privacy. The survey data showed that the average monthly electricity bills per dwelling was about 150 LYD while the total annual electricity consumption per house was approximately 58,000 kWh.

Interview with professional in Benghazi showed that western architecture has both positive and negative impacts on Libyan traditional architecture style. The positive effects involve the provisions of modern materials and construction techniques while the negative impacts involve a lack of proper consideration for climatic variables and socio-cultural factors like privacy. All professionals agreed that sustainable houses could be encouraged in the study context through the adoption of social and climatic design principles. Moreover, the respondents agreed that to enhance privacy, improve comfort and reduce energy consumption in buildings, it was necessary to incorporate important elements of traditional architecture in the design of contemporary dwellings.

These findings showed that there is an urgent need to design residential buildings that satisfy occupants' need in terms of socio-cultural factors, comfort, and energy consumption among other factors. This research aims to achieve this through the development of a framework for designing energy-efficient buildings.

6.0CHAPTER SIX: CASE STUDY SIMULATION AND IMPROVED CASE STUDY

6.1 Introduction

This chapter presents the case study of an existing villa in the study context and the improvement measures conducted on it to determine the possible savings, especially in terms of operative temperature and energy consumption. The chapter, which comprises of two major sections commenced with the case study building in section 6.2. The areas of focus in this section include building information, building construction details, measurements, an overview of DesignBuilder and EnergyPlus and the building simulation results and analysis. Section 6.3 presents the improvement measures on the existing case study and the comparison between the existing building and the improved case study. Finally, section 6.4 concludes this chapter.

6.2 Existing case study

6.2.1 Building Information

A typical contemporary Benghazi house (villa) has been chosen as a case study for existing buildings. In general, most modern Benghazi villas do not have a courtyard. Hence, a detached villa without a courtyard has been selected to determine its performance, especially in terms of comfort and energy consumption.

The building is located in a typical scheme according to a government master plan for the city of Benghazi. The building whose total area is 255m^2 (ground floor) comprises of two floors, ground, and first floors. The functional spaces on the ground floor are the main living room, guest rooms (men and women), kitchen and dining. The first floor consists of bedrooms, banquet room. Figure 6-2 and Figure 6-1 show the ground floor and section of the existing case study. The building is sheltered on three sides by buildings belonging to neighbours. The family size is six, which is the same as the average number of a Libyan family. The measurement and observational survey for the case study were conducted by the researcher on the 14th of August 2016 and the time for the visit was 4 pm. Other information about the case study can be found in Table **6-1**.

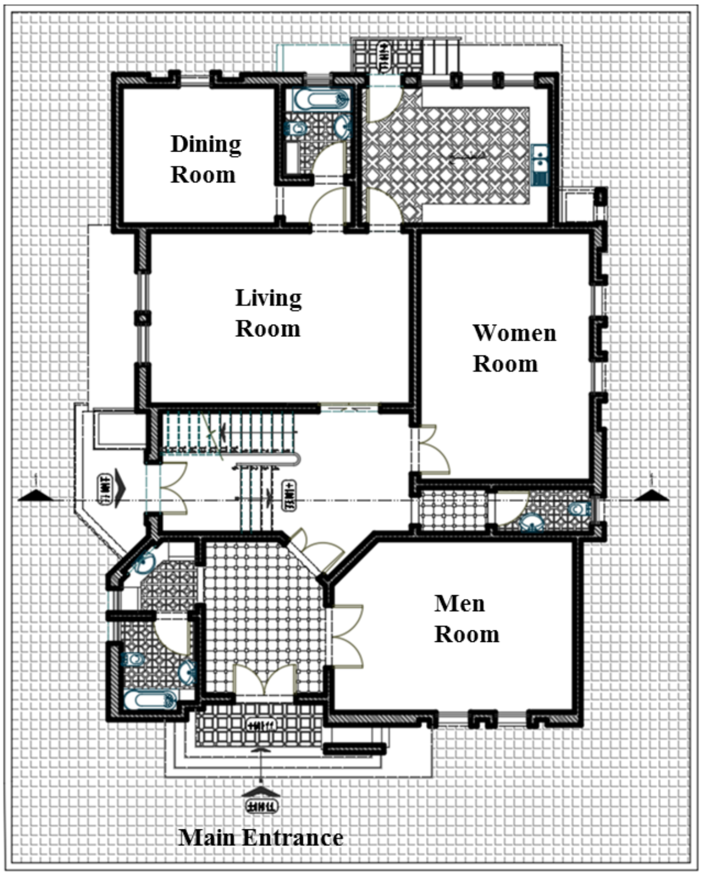


Figure 6-1 the ground floor of existing case study

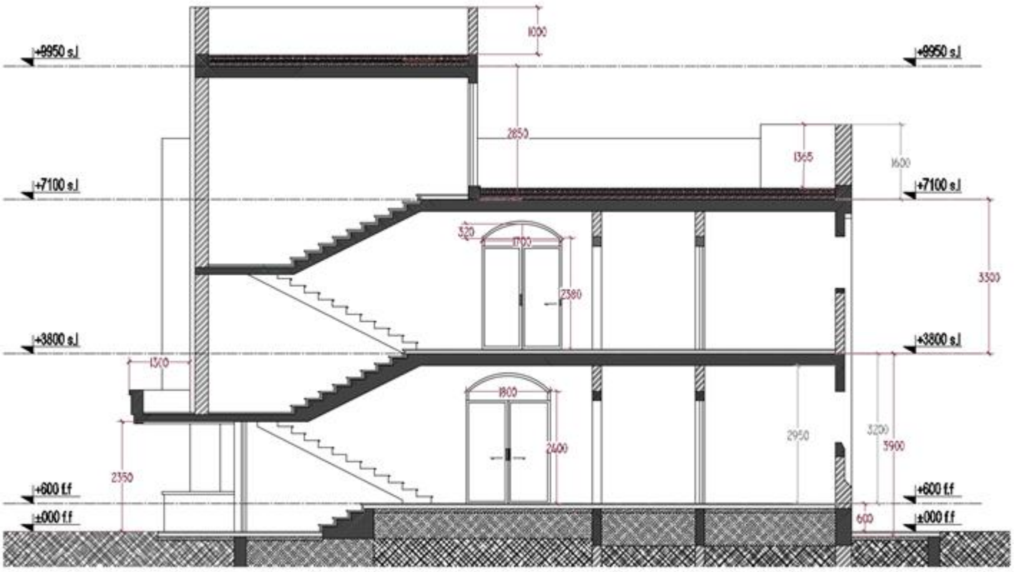


Figure 6-2 the section of existing case study

Table 6-1 Existing case study information

Building Information	
Building orientation	10^0NW
Site area	500m^2
Total Area of outdoor open space	245m^2
Ground floor slab material	200mm thick Concrete slab
First floor slab material	200mm thick reinforced Concrete slab
Wall material	200x200x400mm concrete hollow block
Window type	Sliding
Window glazing	Single glazing clear
Glazed area	43.32m^2
Building height	8.7m
Roof material	Reinforced concrete slab
Building cooling system	Mix-mode (natural ventilation and AC)
Occupancy density (people/area)	6/510= 0.0118 p/m^2
Average electricity bills per month	150 LYD/Month

6.2.2 Building Construction Details

The construction of the building envelope in is without insulation. This is common in residential buildings in Benghazi. The building consists of two floors, the ground floor, and the first floor. The ground floor is made up of three layers, 10mm ceramic porcelain tiles inner layer, 20mm cement mortar, and 200mm concrete slab outer layer. The first floor has four layers, which are the 10mm gypsum plaster, 200mm reinforced concrete slab, 20mm cement mortar, and 10mm ceramic porcelain tiles. The walls consist of mainly 3 layers, which are the outer layer, 10mm cement/mortar render, 200mm hollow concrete block and 10mm cement/sand plaster. Both the internal and external walls are painted with two layers of cream colour emulsion paints. The roof has five layers, 10mm gypsum plaster outer layer, 200mm reinforced concrete slab, 10mm asphalt; 20mm cement mortar and 10mm ceramic tiles.

6.2.3 Measurements

During the survey, the researcher conducted measurement of temperatures, airspeed and humidity for outside, outdoor open space and indoor open space. The level of clothing for householders was determined based on observation. The mechanical cooling systems were active during the time of measurement. Based on the measurement conducted, the AMV and the PMV were calculated to be neutral at (0) and (0.46). The operative temperature at which the AMV and the PMV were both neutral was 24.5^{0}C. The MRT for indoor, outdoor open space and outdoor were 27.1^{0}C, 30.2^{0}C and 32.0^{0}C respectively. This shows a significant difference between the MRTs for the spaces. Tables 6-2 show all measurements for indoor (room), outdoor open space and outdoor (street) respectively.

Table 6-2 all measurements for indoor (room), outdoor open space and outdoor (street)

Room Temperature										
Dry-bulb (^{0}C)	Wet-bulb (^{0}C)	Average of Air Speed (m/s)	Globe Temperature (^{0}C)	Humidity (%)	Clothing Level (clo)	AMV	PMV	MRT (^{0}C)	PPD (%)	Operative Temperature (^{0}C)
25.7	17.6	0.1	26.5	44	0.61	0	0.26	27.1	6	26.4

Open Space Temperature					
Dry-bulb (^{0}C)	Wet-bulb (^{0}C)	Average of Air Speed (m/s)	Globe Temperature (^{0}C)	Humidity (%)	MRT (^{0}C)
28.5	21.9	1.8	28.9	57	30.0

Outdoor Temperature					
Dry-bulb (^{0}C)	Wet-bulb (^{0}C)	Average of Air Speed (m/s)	Globe Temperature (^{0}C)	Humidity (%)	MRT (^{0}C)
28.8	25.1	2.15	29.5	76	30.2

6.2.3.1 Modelling of Case Study in DesignBuilder

This section details the materials selected in DB for the modelling and simulation of the case study. The elements of the building envelope considered are the floor, walls, roof, and windows. The details for the floor, walls and roof construction of the case study has been presented in section 6.2.2. The construction details and the thermo-physical properties of the building used for modelling in DB are illustrated in

Table 6-3. The window to wall ratio was calculated at 8.23%. All the windows in the building are sliding and have single glazing, clear with no shading devices. The material for the window frame is polyvinyl chloride (PVC). This information is used in DB to model the windows for the case study. Figure 6-3 shows the 3D model of the existing case study showing the surrounding buildings.

Table 6-3 the construction details of the ground floor, walls, and roof

Building element	Material description	Thickness (mm)	R-Value and U-Value
Ground Floor			**R-Value** 0.516 m^2-k/W
	Ceramic porcelain tiles	10	
	Cement mortar	20	**U-Value** 1.936 W/m^2-k
	Concrete slab	200	
Walls			**R-Value** 0.516 m^2-k/W
	Gypsum plaster	15	
	Concrete hollow block	200	**U-Value** 1.936 W/m^2-k
	Cement/mortar render	10	
Roof			**R-Value** 0.422 m^2-k/W
	Ceramic Tiles	10	
	Cement mortar	20	
	Asphalt	10	**U-Value** 2.369 W/m^2-k
	Reinforced concrete slab	200	
	Cement/plaster/mortar-Gypsum plaster	10	

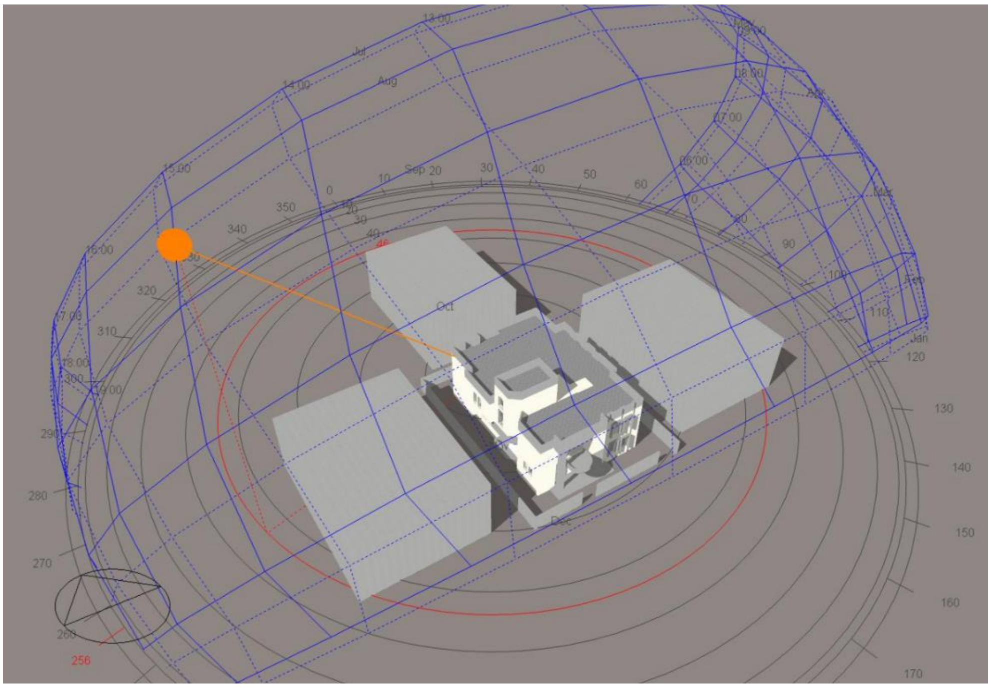


Figure 6-3 the 3D model of the existing case study showing surrounding buildings

6.2.4 Building Simulation Results and Analysis

The analysis of the simulation will be presented under orientation and sun path analysis, daylighting analysis, analysis of simulation results using natural and mechanical cooling.

6.2.4.1 Orientation and Sun Paths Analysis

The orientation of the existing villa is 10^0NW and this was used for modelling in DesignBuilder. Based on this orientation, the longer axis of the building is faced east-west. The western side of the building is affected by the sun from afternoon to evening. The rooms on the first floor are exposed to high solar gain making them not comfortable for householders to use in the afternoon and evening. Neighbouring building on the west side provided adequate shading for the rooms on the ground floor. The building orientation is against the recommendation that the long axis of buildings should face the north-south axis to minimise heat gain and improve thermal comfort (Elaiab, 2014). Figure 6-3 shows the sun paths diagram in the building at 3 pm on the 15^{th} of July.

6.2.4.2 Daylighting Analysis

The case study is sheltered on three sides by other buildings. This affects the level of daylighting in the building. The window to wall ratio (WWR) was calculated at 8.23%.

This very low and will significantly affect the daylight factor in the building. Previous studies have recommended WWR of 20% (Tantasavasdi et al., 2001) and 24% (Liping and Hien, 2007) for adequate daylighting in buildings in Singapore and Thailand respectively. The total area of both ground and first floors is 441.46m^2. The total average daylight factor, the total minimum daylight factor and the total floor above threshold in square meter are 22.1%, 0.89%, and 26.536m^2. No space in case study met the low daylight factor of 2%. Figure 6-4 shows the daylighting simulation results for the ground floor and Figure 6-5 the 3D daylighting for the ground floor of the existing case study.

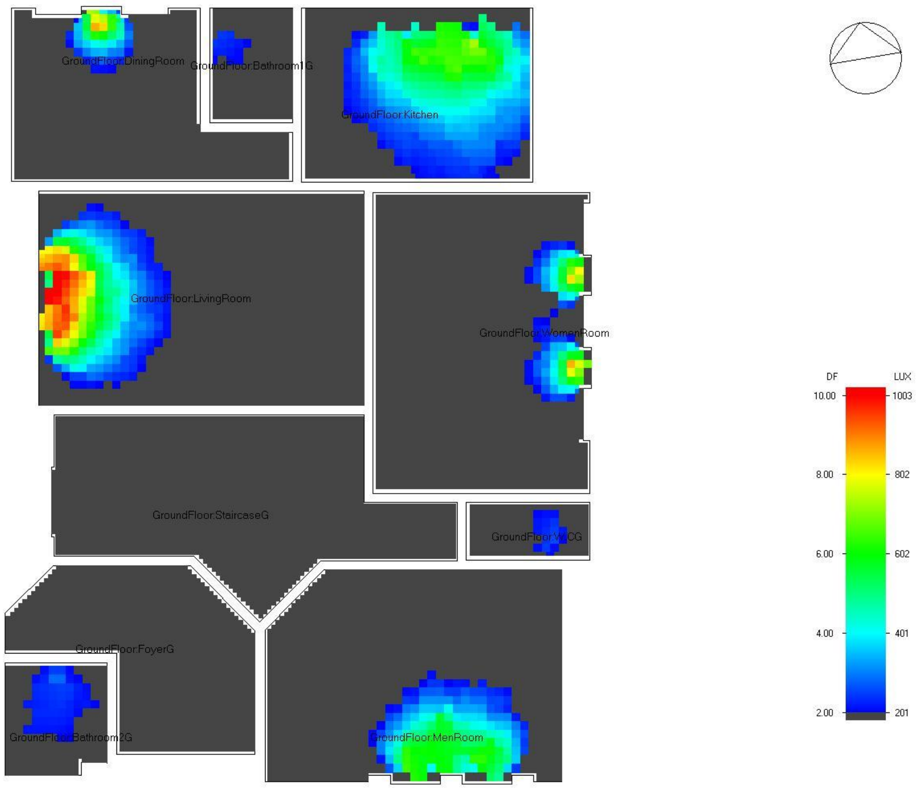


Figure 6-4 the daylighting simulation for the ground floor

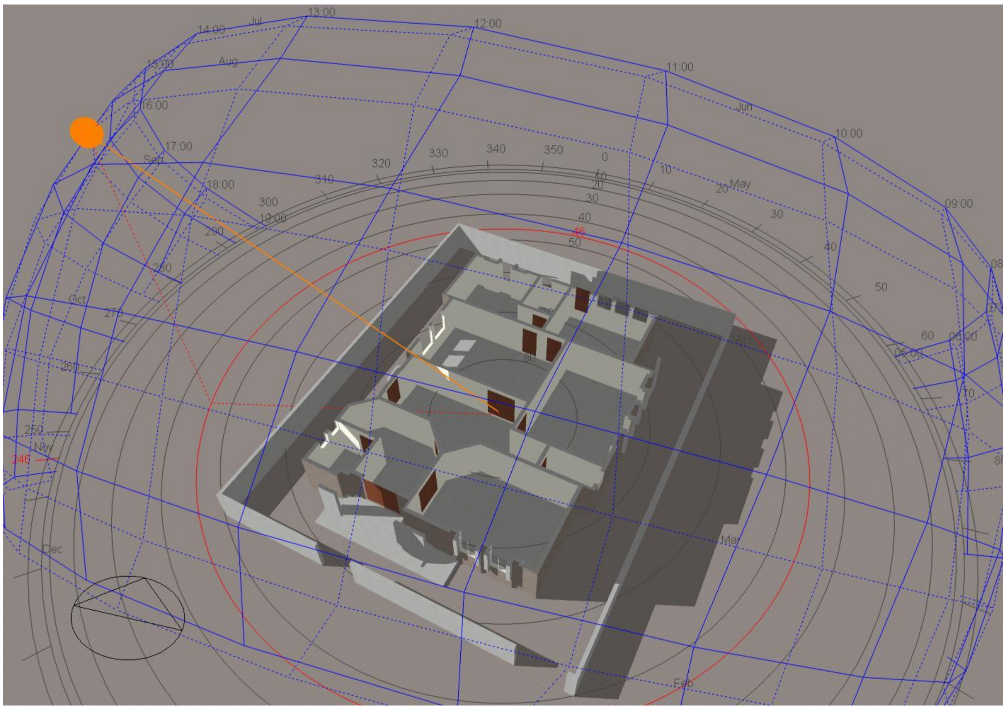


Figure 6-5 the 3D daylighting for the ground floor

6.2.4.3 BREEAM Health Wellbeing Credit HEA1

The daylighting in the case study failed against BREEAM Health Wellbeing Credit HEA1. This standard aims to encourage and recognise building designs, which made provision for proper levels of daylighting for building occupants. A building will receive a pass credit if it meets the following requirements:

a. 80% of the total floor area has adequate daylight with minimum average daylight factor of 2% at 700mm height working plane using uniform CIE overcast design sky.
b. Minimum uniformity ratio of 0.4 or at least 0.8% minimum point daylight facto.

Table 6-4 shows the summary of the simulation results while Table 6-5 shows the eligible zones for daylighting simulation result for the case study.

Table 6-4 summary of the daylighting simulation results

Summary Results	
Total area (m2)	441.457
Total area above threshold (m2)	26.536
% Area above illuminance threshold	0.0
Criterion a) 80% of area adequately daylit	FAIL
Criterion b) Uniformity ratio >= 0.3, min DF = 0.8%	FAIL
BREEAM Health and Wellbeing Credit HEA01 Status	FAIL

Table 6-5 the eligible zones for daylighting simulation result for the existing case study

Zone	Block	Floor area (m2)	Min DF (%)	Uniformity ratio (Min / Avg)	Average Daylight Factor (%)
GroundFloor:DiningRoom	Ground Floor	20.666	0.00	0.00	0.7
GroundFloor:Bathroom1G	Ground Floor	5.386	0.07	0.07	1.0
GroundFloor:Kitchen	Ground Floor	22.536	0.08	0.03	3.0
GroundFloor:WomenRoom	Ground Floor	36.160	0.01	0.01	0.8
GroundFloor:LivingRoom	Ground Floor	39.201	0.09	0.05	1.8
GroundFloor:MenRoom	Ground Floor	34.277	0.02	0.01	1.3
GroundFloor:FoyerG	Ground Floor	18.334	0.00	0.00	0.0
GroundFloor:Bathroom2G	Ground Floor	6.276	0.09	0.06	1.5
GroundFloor:W.CG	Ground Floor	3.965	0.10	0.08	1.3
FirstFloor:Bathroom1F	First Floor	5.527	0.12	0.07	1.7
FirstFloor:Bedroom1	First Floor	21.663	0.02	0.02	1.0
FirstFloor:MasterBedroom	First Floor	38.342	0.00	0.00	0.7
FirstFloor:StaricaseF	First Floor	49.271	0.00	0.00	0.9
FirstFloor:Bedroom3	First Floor	20.262	0.01	0.01	0.7
FirstFloor:FoyerF	First Floor	20.116	0.00	0.00	0.0
FirstFloor:Bedroom2	First Floor	20.638	0.01	0.01	0.7
FirstFloor:BathroomMaster	First Floor	8.359	0.04	0.03	1.3
FirstFloor:ReceptionRoomF	First Floor	66.478	0.01	0.01	1.4
FirstFloor:W.CF	First Floor	4.000	0.22	0.10	2.3
Total		**441.457**			

6.2.4.4 Simulation Using Natural Ventilation

The simulation of the case study was first conducted using natural ventilation, no heating, and cooling in DB. This was to determine the performance of the existing building, especially in terms of thermal comfort and energy consumption. The simulation results are hereby discussed under thermal comfort and energy consumption.

a. Thermal Comfort

Although it was discovered through the survey of 72 householders that all buildings depend majorly on mechanical cooling to achieve comfort, simulation of the case study will be conducted to compare thermal comfort using natural ventilation with mechanical cooling. Increase in outdoor temperature from the months of June to September has a significant effect on thermal comfort in dwellings. It was found from the survey that people are comfortable in buildings at an operative temperature between 25^{0}C - 26^{0}C (neutral on ASHRAE sensation scale). The simulation results using natural ventilation shows that people will be comfortable from the month of November to April in their dwellings as temperature ranges from 24.12^{0}C to 24.21^{0}C. The results also indicated that there is thermal discomfort in a dwelling from the months of May to September. The lowest and the highest operative temperature are 27.91^{0}C in May and 32.18^{0}C in July respectively. Figure 6-6 shows the monthly simulation results for comfort in summer times.

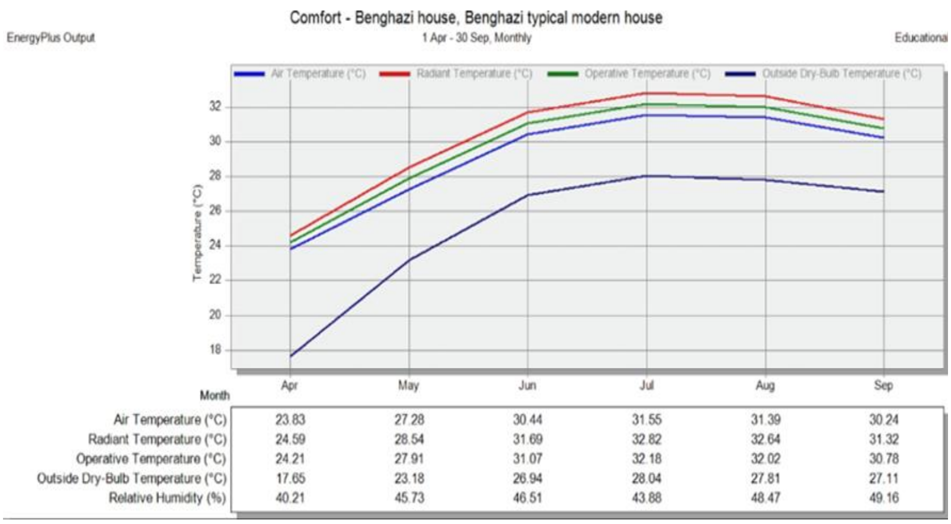


Figure 6-6 the monthly simulation results for comfort in summer months.

b. Energy Consumption

The total annual energy consumption using natural ventilation is 24, 977.79kWh. Energy consumption for room electricity, lighting, domestic hot water (DWH), exterior lighting is 2901.06kWh, 21407.56 kWh, 473.82 kWh, and 195.35 kWh respectively. Figure 6-7 and Figure 6-8 show the annual fuel totals and monthly fuel breakdown. The major energy consumption for the dwelling is for artificial lighting at 21407.56 kWh. The survey also confirmed that people depend on artificial lighting even during the day in their dwellings leading to high-energy consumption in buildings. This may be because of the findings from the observation and survey of existing villas, which revealed inadequate daylighting in dwellings due to challenges with building orientation, use of drapes on windows for privacy and low energy cost in Libya. Moreover, incandescent bulb is used extensively in buildings with its high-energy demand.

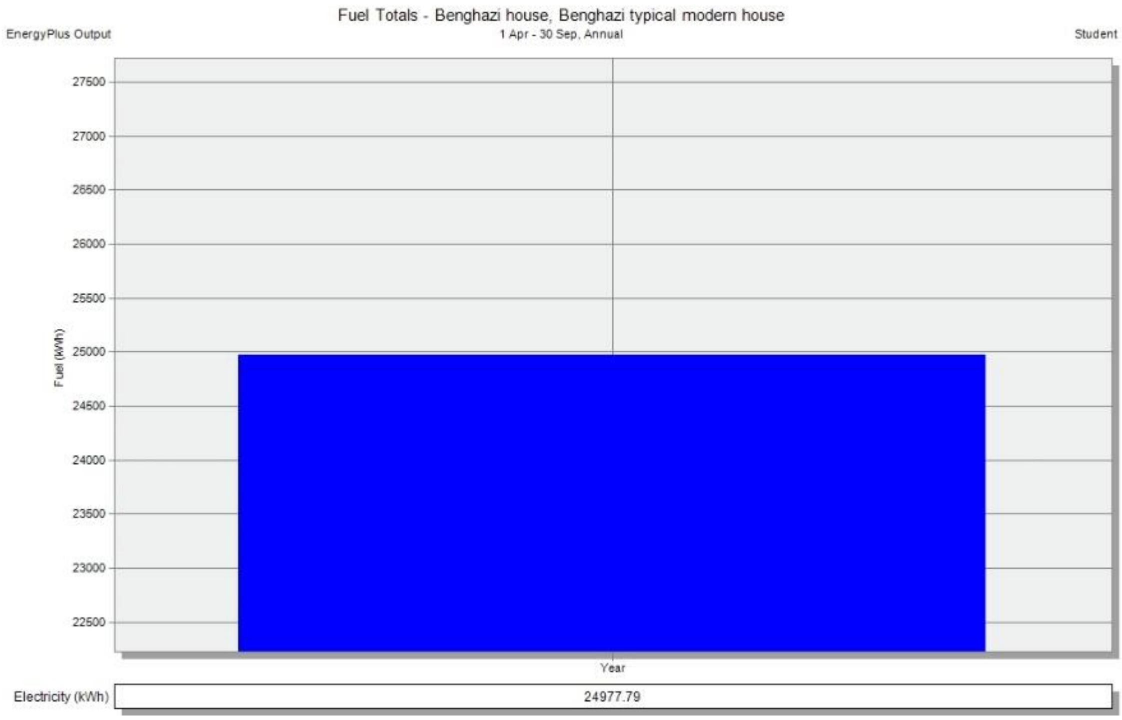


Figure 6-7 the annual fuel totals

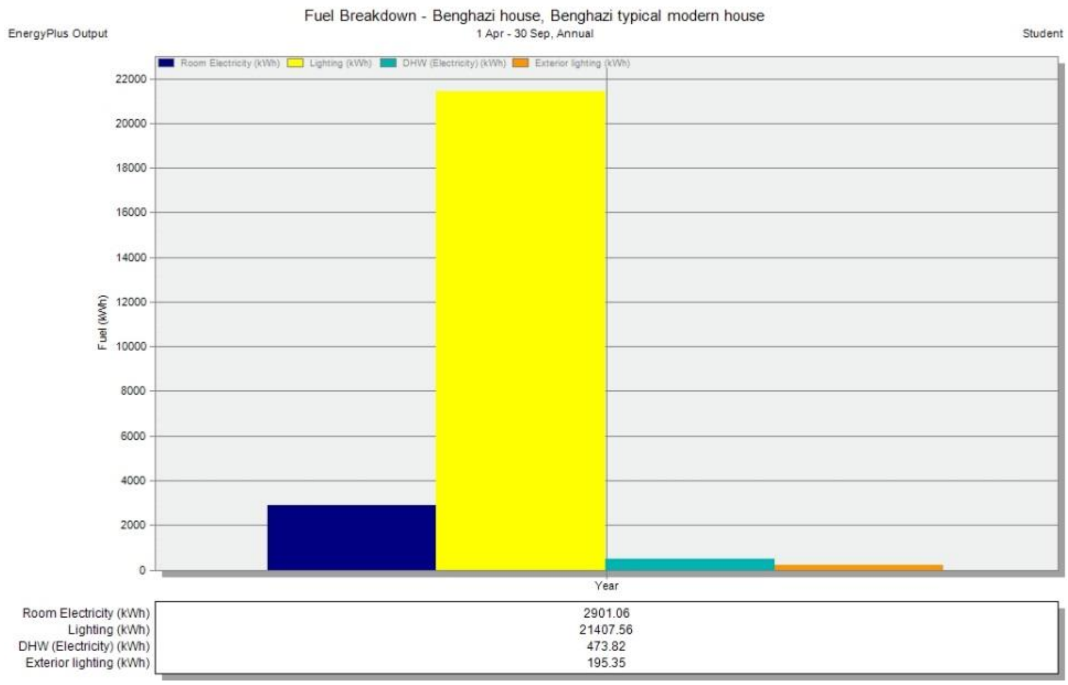


Figure 6-8 the monthly fuel breakdown

The solar gains through interior windows and exterior windows are 1146.45kWh and 9162.80kWh respectively. It is evident that the highest solar gains in through the external windows. Improvement of external window shadings and glazing types can reduce the solar gains. Figure 6-9 shows the internal gains and solar gains in the case study.

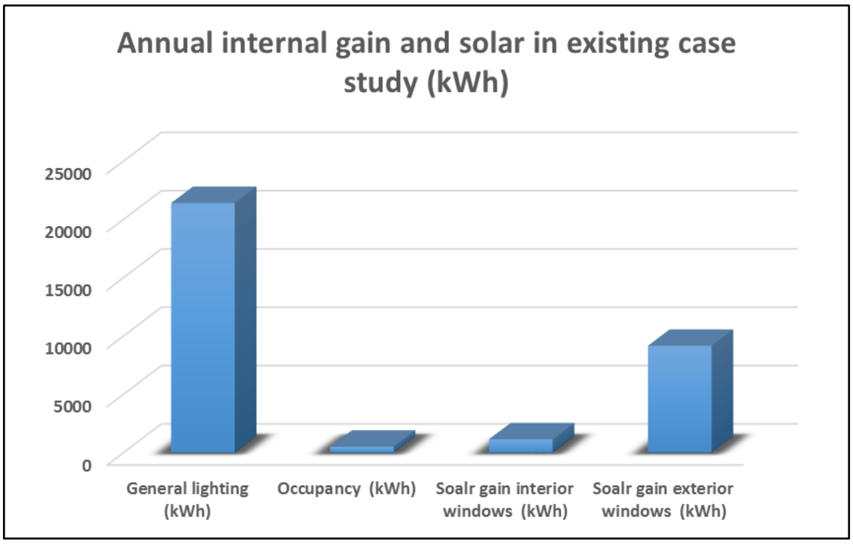


Figure 6-9 the internal gains and solar gains in the existing case study

6.2.4.5 Simulation Using Mechanical Cooling

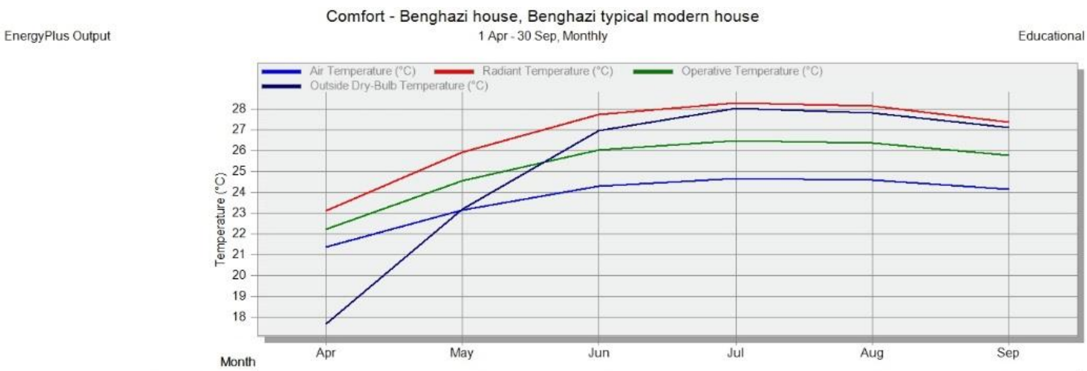
As discussed earlier, the survey of 72 householders in Benghazi reveals that all the buildings depend on mechanical cooling systems to achieve thermal comfort, especially during summer. Increase in outdoor temperature from the months of April to September has a significant effect on the use of ACs in dwellings. The interview conducted with design professions (architects and engineers) confirmed the huge dependence of mechanical cooling for thermal comfort in buildings.

The simulation of the case study was conducted using mechanical cooling systems for thermal comfort and energy consumption. The case study uses a split unit ACs just like all the dwellings surveyed and the cooling system coefficient of performance (CoP) was 3.5. Hence, the split AC system was used as the HVAC template in DesignBuilder for simulation. The survey and the simulation results show that heating is not required in buildings.

a. Thermal Comfort

The cooling set point for simulation was 25^{0}C while the cooling setback was 28^{0}C. These set points were determined from survey, measurement and literature review.

The lowest operative temperature was recorded in the month of April at 22.22^{0}C while the highest operative temperature was for July at 26.48^{0}C. Figure **6-10** shows the simulation results for comfort using mechanical ventilation.



Month	Apr	May	Jun	Jul	Aug	Sep
Air Temperature (°C)	21.35	23.14	24.30	24.67	24.58	24.13
Radiant Temperature (°C)	23.10	25.93	27.72	28.29	28.14	27.37
Operative Temperature (°C)	22.22	24.54	26.01	26.48	26.36	25.75
Outside Dry-Bulb Temperature (°C)	17.65	23.18	26.94	28.04	27.81	27.11
Relative Humidity (%)	46.24	58.57	63.26	61.56	64.80	65.20

Figure 6-10 the simulation results for comfort using mechanical ventilation

b. Energy Consumption

The total energy consumption using mechanical cooling was 54,009.83kWh. This is almost twice the energy consumption in the building using only natural ventilation. Also, it is nearly to the total annual energy consumption per house, which has been calculated in chapter 5 section 5.4.7, which is 58258.06 kWh.

The energy consumption for lighting, cooling, DHW, and exterior lighting were 21407.56 kWh, 32143.38kWh, 263.54kWh and 195.35kWh respectively. This shows that the highest energy consumption for the building was due to cooling load at 32143.38kWh. This means the total energy consumption for space cooling in kWh/m^2 per year is 72. The European Standard recommended 20-30kWh/m2 per year in terms of total annual energy for space cooling (Carmody et al., 2009). This suggests the need to drastically reduced cooling load in dwellings. The annual CO_2 emission using mechanical cooling was 36996.73kg**.** Figure 6-11 shows the annual fuel totals while Figure 6-12 shows the fuel breakdown for the case study using mechanical cooling.

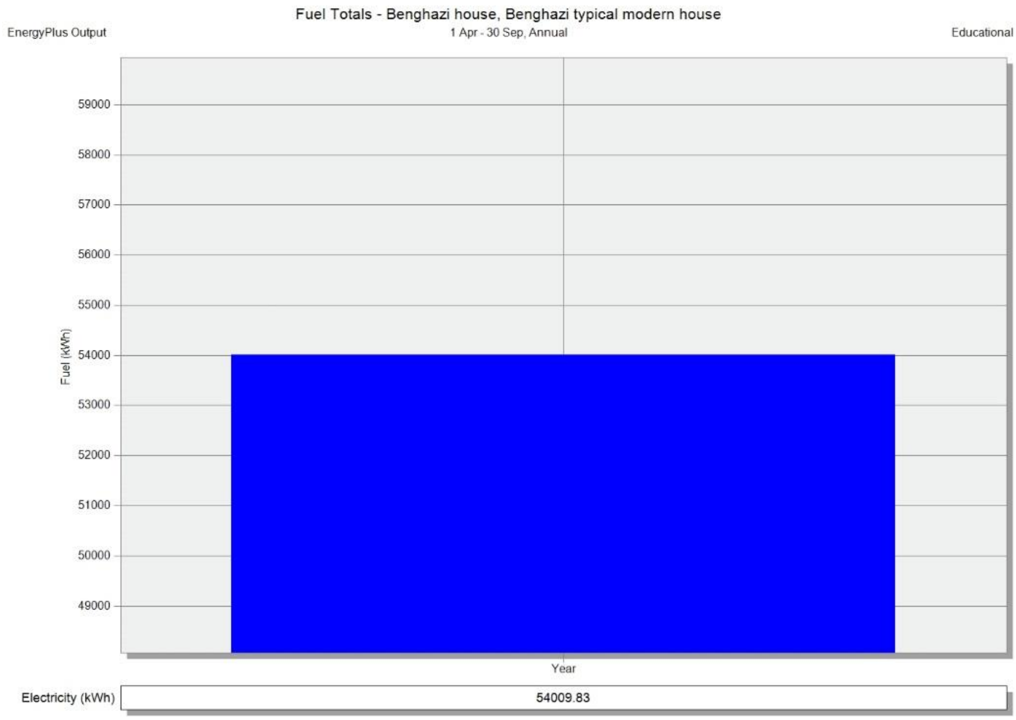


Figure 6-11 the annual fuel totals using mechanical cooling

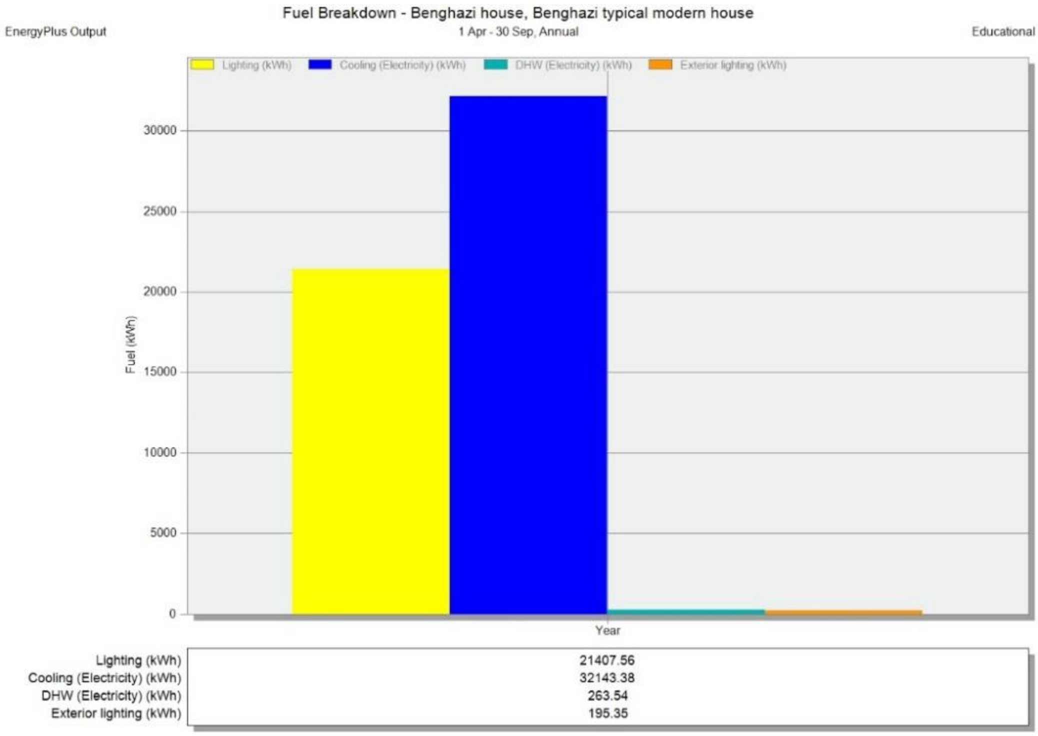
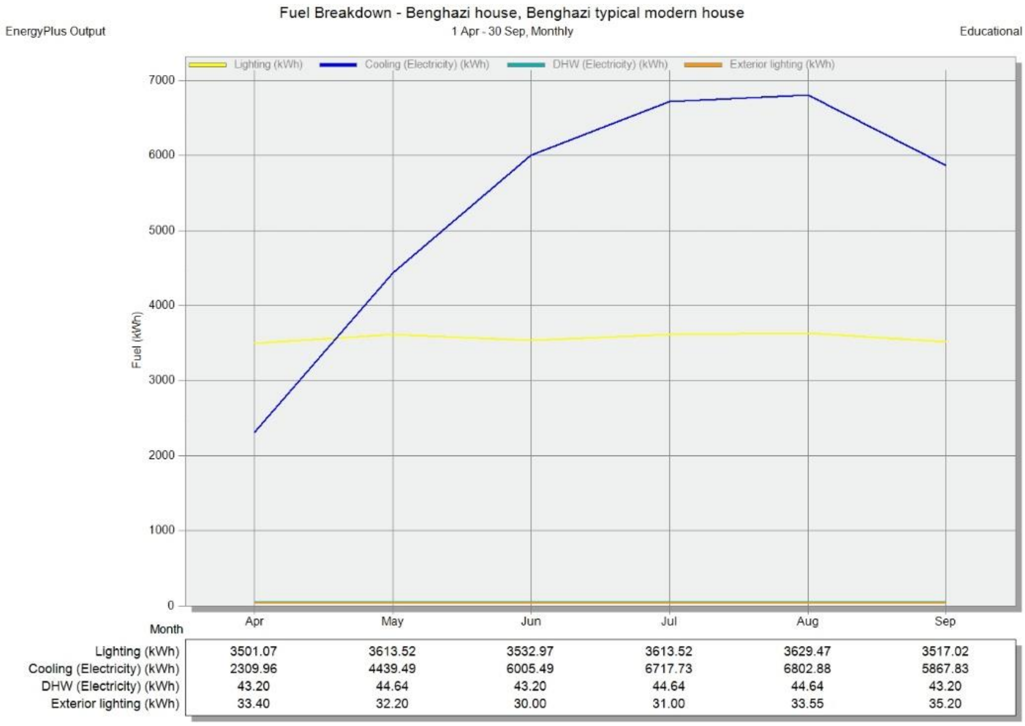


Figure 6-12 the fuel breakdown for the existing case study using mechanical cooling

In terms of fuel breakdown through the summer months, electricity for cooling was the highest energy consumption in July and August with 6717.73 kWh and 6802.88 kWh respectively because of high temperatures. In addition, the highest energy consumption due to lighting was in July with 3613.52 kWh and in August with 3629.47 kWh. Therefore, the major consideration for reducing energy demand will be focusing on July and August. Figure - shows the fuel breakdown through the summer months.



Month	Apr	May	Jun	Jul	Aug	Sep
Lighting (kWh)	3501.07	3613.52	3532.97	3613.52	3629.47	3517.02
Cooling (Electricity) (kWh)	2309.96	4439.49	6005.49	6717.73	6802.88	5867.83
DHW (Electricity) (kWh)	43.20	44.64	43.20	44.64	44.64	43.20
Exterior lighting (kWh)	33.40	32.20	30.00	31.00	33.55	35.20

Figure 6-13 the fuel breakdown through summer months

6.3 Improved case study

This section documents the improvement conducted on the existing building in terms of orientation, windows, external walls, ground floor slab, roof and lighting. The existing building is first improved for orientation and each of the parameters for possible savings based on operative temperature using natural ventilation only. The improved building is then simulated and compared with the existing building in terms of energy consumption only. This is to determine the improvement made between the existing building and the improved building based the particular parameter. At the end of the improvement based on individual parameters, the whole improved building is simulated and compared with the existing building regarding operative temperature using natural ventilation only. After this, both the existing and the improved buildings were then simulated to determine the saving in terms of energy consumption. The assumptions made for the simulation of the improved case study regarding natural ventilation and mechanical cooling systems are discussed below.

- **Assumption for simulation using natural ventilation**

some assumptions were made for the simulation of the improved case study using natural ventilation. Air changes per hour (ac/h) of 3 was assumed due to the use of blinds in study context, which can hinder air movement. Air definition method was by zone and operation schedule was for residential spaces according to the various zones. The windows were assumed to be opened by 100% since casement window.

- **Assumption for simulation using mechanical cooling systems**

Just like in the simulation of the improved case study using natural ventilation, some assumptions were also made for the simulation of the prototype deign using mechanical cooling systems (Split AC). The cooling system coefficient of performance (CoP) was assumed to be 3.5. The minimum suply of air temperture and humidity ratio of 12^0C and 0.008g/g were assumed respectively. The survey of existing villas revealed that ACs are used all the time in buildings during summer months. Hence, the simulation of the the improved case study was based on the assumption that ACs were used all the time.

6.3.1 Improvement on existing building based on individual parameters

This section presents discussion on the various improvement made to the existing building based on individual parameters.

6.3.1.1 Orientation

As discussed earlier in this thesis, building orientation is important in reducing energy demand in buildings. Hence, the need to investigate the effect of different orientation on the on the existing building.

The orientation of the existing building is 10^0NW. The orientation was tested using 0^0, 90^0, 180^0 and 270^0 for possible difference in annual operative temperature using natural ventilation. The simulation results indicated that the best orientation is 90^0E as in Figure 6-14 . By using this orientation, the simulation using natural ventilation showed just 0.03^0C decreasing in annual operative temperature while the simulation using AC showed just 0.02% savings in annual energy demand.

Table **6-6** shows the annual operative temperature of the existing building orientation and the four other options investigated. Table 6-7 shows the energy consumption of the existing building orientation and the four other options.

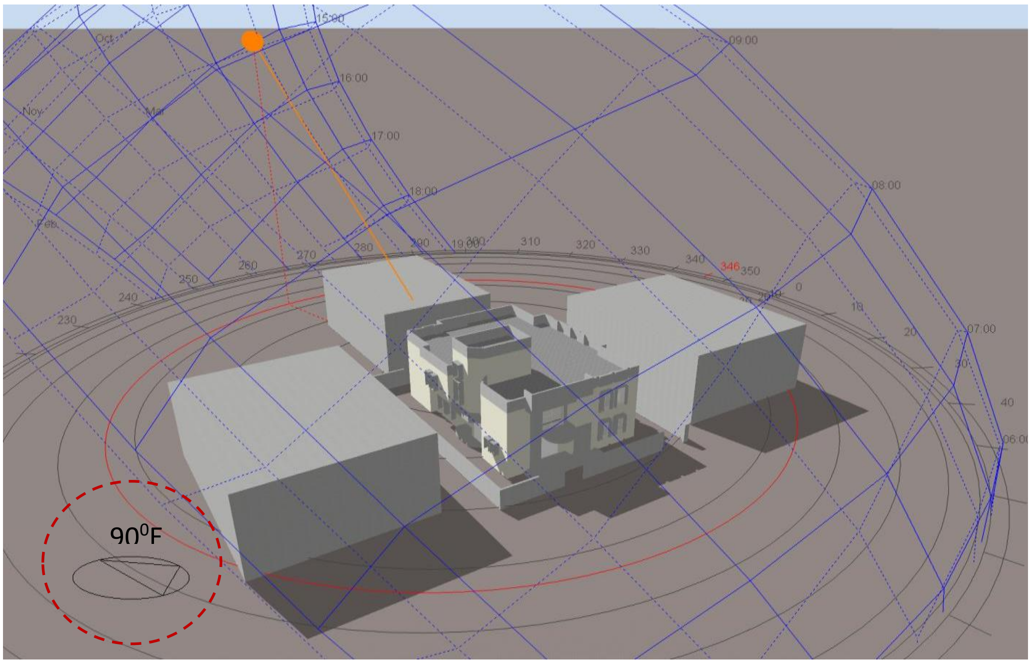


Figure 6-14 the best orientation is 90^{0}E

Table 6-6 the annual operative temperature of the existing building orientation and the four other options

Orientation	Annual Operative Temperature (T_{op}) ^{0}C - (Natural ventilation)	
	Improved existing case study	Existing case study (10^{0}NW)
0° N	27.19	27.19
90° E	27.16	
180° S	27.19	
270° W	27.18	

Table 6-7 the energy consumption of the existing building orientation and the four other options

Orientation	Annual energy consumption (kWh) – AC	
	Improved existing case study	Existing case study (10^{0}NW)
0° N	54115.27	54009.83
90° E	54000.95	
180° S	54225.75	
270° W	54394.63	

6.3.1.2 Windows

Buildings in Benghazi use single glazing clear glass windows. Hence, the existing was modelled using this type of glass. The improved building was modelled using double-glazing, internal blinds glazing template. The glazing type was double glazing clear glass (Dbl Clr 6mm/6mm air) having total solar transmission (SHGC) of 0.7, direct solar transmission of 0.6 and light transmission of 0.7. The U-Value based on ISO 15099/NFRC is 3.094 W/m2K. The material for the window frame is PVC while close weave medium drapes having solar transmittance of 0.05 and conductivity of 0.1 W/Mk was assumed for window shading. The first option for window was modelled without local shading while the second option modelled and simulated with 500mm wide overhang and side fins (500mm projection) made of concrete as in Figure **6-15** .

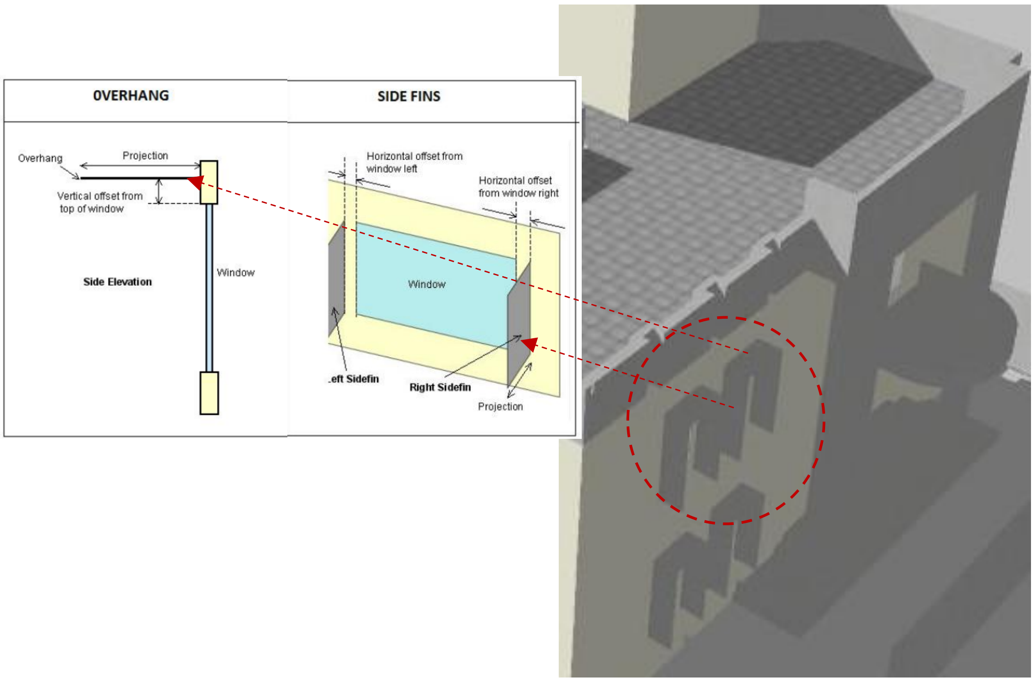


Figure 6-15 shading windows with wide overhang and side fins

The simulation results for the first option without local shading in terms of operative temperature for July (hottest month) is 29.72^{0}C whereas the second option with local shading resulted in July operative temperature of 29.35^{0}C. Hence, the second option was adopted as the preferred alternative. The existing building, which uses single glazing clear glass with no local shading, has operative temperature of 32.18^{0}C in July as in Table 6-8. Both the existing building and the improved building (the second alternative window) were then simulated using ACs for their performances in terms of energy demand. Table 6-9 illustrates the results, which showed 20.9% reduction in terms of energy demand.

Table 6-8 Average of Operative Temperature for existing case study and improved windows

Windows options	Average of Operative Temperature of July (Top)°C - (Natural ventilation)	
	Improved existing case study	Existing case study
1- Double glazing clear glass (Dbl Clr 6mm/6mm air)	29.72	32.18
2- Double glazing clear glass (Dbl Clr 6mm/6mm air) with local shading	29.35	

Table 6-9 Annual energy consumption for existing case study and improved windows

Windows option 2	Annual energy consumption (kWh) – AC		
	Improved existing case study	Existing case study	Reduction %
2- Double glazing clear glass (Dbl Clr 6mm/6mm air) with local shading	42735.5	54009.83	20.9%

6.3.1.3 External walls

In order to determine the most suitable wall to buildings in the study context, two wall types were investigated for the external walls. These are cavity and insulated walls. The parameters for the modelling and simulation of the two types of wall are presented in this section.

a. External cavity wall

The cavity block was modelled in five layers. The materials for the outer and inner layers are a concrete hollow block of 200mm and 100mm respectively. While the outer layer was finished with cement/mortar render, the inner layer was rendered with gypsum plaster. The air gap between the outer and inner layer (cavity) is 50mm wide. Figure **6-16** shows a section through the cavity wall and Table **6-10** shows the construction materials for the cavity wall.

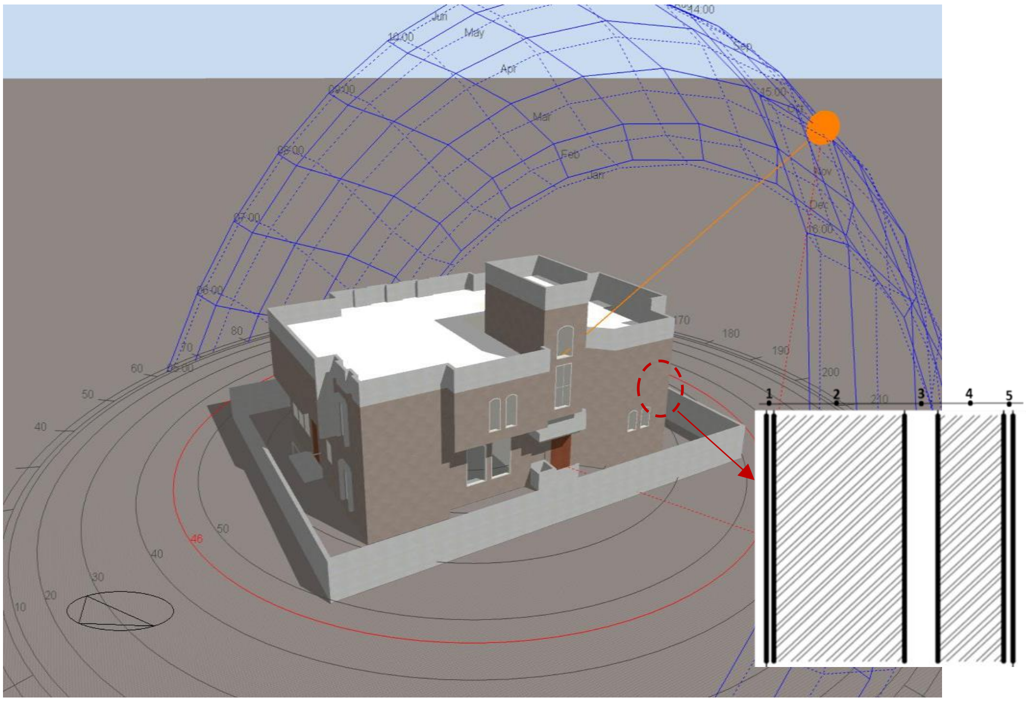


Figure 6-16 a section through the cavity wall

Table 6-10 the construction materials for the cavity wall

	External cavity wall	Thickness of layers	R-value(m^2K/W) U-value(W/m^2K)
1 (outer layer)	Cement/mortar render	10mm	R-value= 0.965 U-value=1.036
2	Concrete hollow block	200mm	
3	Air gap	50mm	
4	Concrete hollow block	100mm	
5 (inner layer)	Gypsum plaster	15mm	

The cavity wall was simulated using natural ventilation only and the operative temperature based on the cavity wall was 29.72^{0}C in July, which is the hottest month in the study area. The operative temperature of the existing building based on single leaf concrete block external wall construction was 32.18^{0}C. This shows that the cavity wall performed better in terms of operative temperature. Nevertheless, the researcher thought that it is necessary to investigate insulated walls to compare its performance with a single leaf wall and cavity wall.

b. External insulated wall

Just as the cavity wall discussed earlier, the insulated wall has five layers. The difference is that instead of a cavity of 50mm an insulation of 100mm (polystyrene) was provided and external leaf was 100mm against the cavity wall of 200mm (Ihm & Krarti, 2012). Figure 6-17 shows a section through the insulated wall and Table **6-11** shows the material composition of the insulated wall.

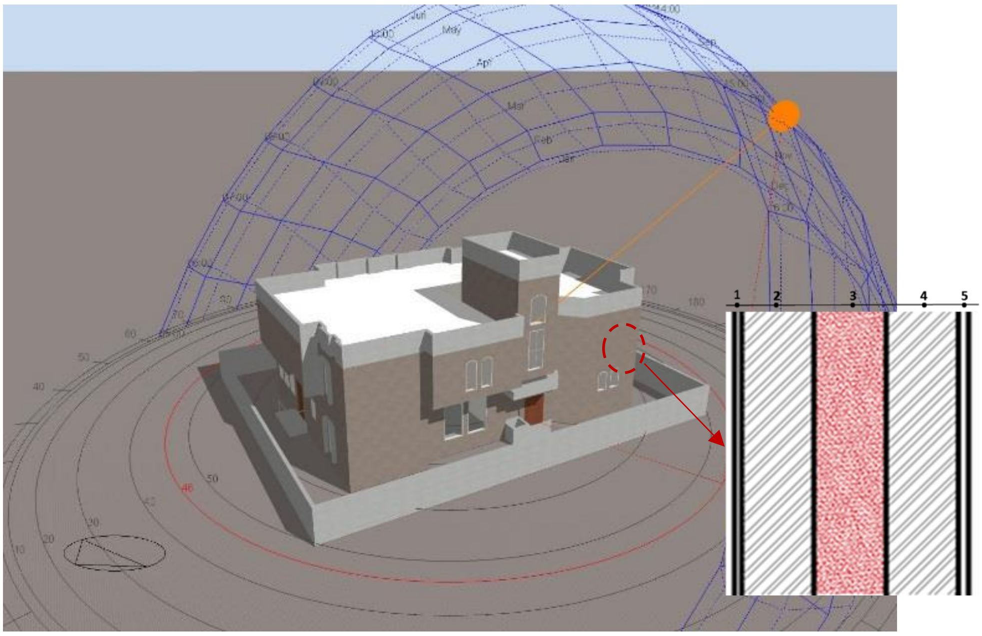


Figure 6-17 a section through the insulated wall

Table 6-11 the material composition of the insulated wall

	External insulation wall	Thickness of layers	R-value(m^2K/W) U-value(W/m^2K)
1 (outer layer)	Cement/mortar render	10mm	R-value= 3.073 U-value= 0.325
2	Concrete hollow block	100mm	
3	Polystyrene (insulation)	100mm	
4	Concrete hollow block	100mm	
5 (inner layer)	Gypsum plaster	15mm	

The simulation results for the external cavity wall in terms of operative temperature for July is 29.72^{0}C whereas the external insulated wall resulted in July operative temperature of 29.31^{0}C. Therefore, the insulated wall was adopted as the preferred alternative. The existing building has an operative temperature of 32.18^{0}C in July as in Table 6-12. Both the existing building and the improved building with insulated wall were then simulated using ACs for their performances in terms of energy demand. Table 6-13 illustrates the results, which showed 33.8% reduction in terms of energy demand.

Table 6-12 Average of Operative Temperature for existing case study and improved external wall

Average of Operative Temperature of July (Top)°C - (Natural ventilation)			
External wall options	Improved existing case study 1- (External cavity wall)	Improved existing case study 2- (External insulation wall)	Existing case study (External wall)
(Top)°C	29.72	29.31	32.18
R-value(m^2K/W) U-value(W/m^2K)	R-value= 0.965 U-value=1.036	R-value= 3.073 U-value= 0.325	R-value= 0.483 U-value= 2.071

Table 6-13 Annual energy consumption for existing case study and external insulated wall

Annual energy consumption (kWh) – AC		
Improved existing case study (External insulation wall)	Existing case study (External uninsulated wall)	Reduction %
35775.39	54009.83	33.8%

6.3.1.4 Ground floor slab

Almost all the buildings in the study area were constructed with concrete floor slab raised from the ground using columns. The interview questionnaire survey of householders in the Benghazi confirmed this as all the buildings visited were constructed with a concrete floor slab. Existing literature revealed that on-ground concrete floor slab is the most suitable for buildings in a hot climate. Hence, there is need to investigate these floor types to determine the best option. The on-ground floor slab was modelled in four layers. Figure 6-18 shows a section through the on-ground concrete floor slab and table 6-14 shows the construction of the ground floor and total R and U-Value.

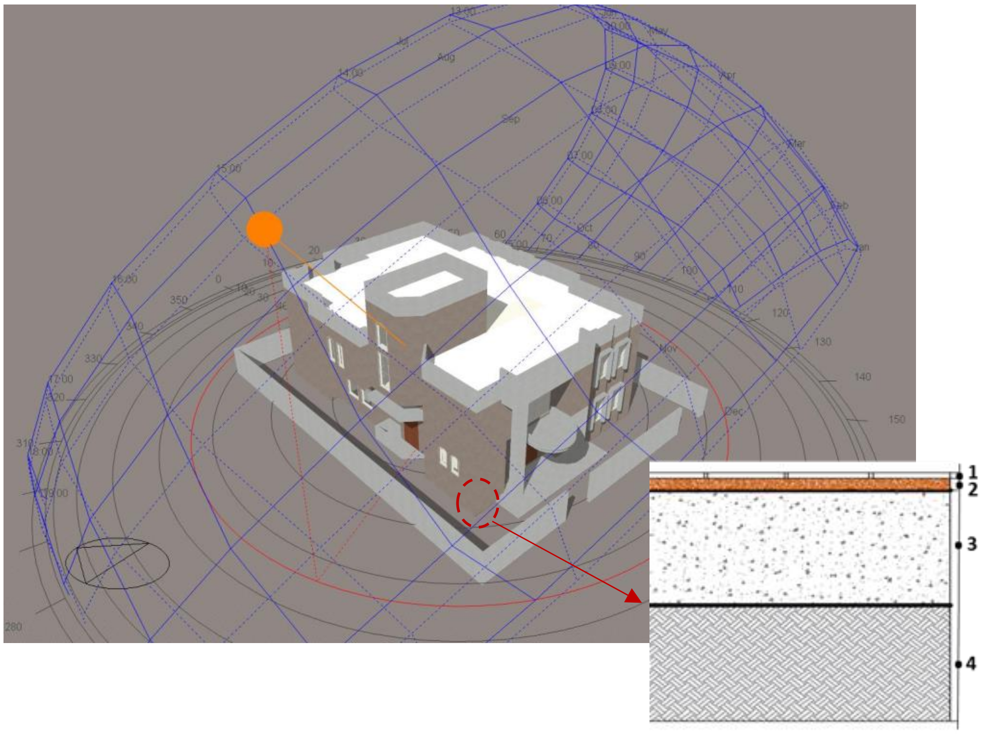


Figure 6-18 a section through the on-ground concrete floor slab

Table 6-14 construction of the ground floor and total R and U-Value

	A new ground floor	Thickness of layers	R-value(m^2K/W) U-value(W/m^2K)
1 (outer layer)	Ceramic porcelain tile	10mm	R-value= 0.613 U-value=1.632
2	Cement mortar	20mm	
3	Concrete slab	200mm	
4 (outer layer)	Compacted earth filling	200mm	

The simulation result of the on-ground concrete floor slab using natural ventilation showed 31.96^{0}C for the month of July. Operative temperature compared to the existing building raised floor construction having an operative temperature of 32.18^{0}C. The on-ground concrete floor slab performed better than the raised floor as used in the study context. Hence, it was adopted as the preferred ground floor slab construction.

Table 6-15 shows the comparison between the existing building and the improved ground floor in terms of Operative Temperature.

The improve building was simulated using AC based on the on-ground concrete floor slab and the result was compared with the simulation result of the existing building (using AC). The results indicated 11.2% savings in terms of energy demand. Table **6-16** shows the simulations results for the existing building and the improved ground floor.

Table 6-15 Average of Operative Temperature for existing case study and improved ground floor

Average of Operative Temperature of July (Top)°C - (Natural ventilation)		
Ground floor slab	Improved existing case study (On-ground concrete floor slab)	Existing case study (Ground floor slab)
(Top)°C	31.96	32.18
R-value(m^2K/W) U-value(W/m^2K)	R-value= 1.646 U-value= 0.608	R-value= 0.613 U-value= 1.632

Table 6-16 Annual energy consumption for existing case study and improved ground floor

Annual energy consumption (kWh) – AC		
Improved existing case study (on-ground concrete floor slab)	Existing case study	Reduction %
47985.09	54009.83	11.2%

6.3.1.5 Roof Insulation

Residential buildings in the study context were always constructed without insulation. All the buildings visited during the survey were without insulation. Hence, the existing case study was simulated without insulation. Previous studies have emphasized the relevance of insulation for residential buildings in hot dry climate. This forms the main reason why the effect of insulation on residential building studied in this section. Polystyrene insulation of 100mm was assumed for the roof construction (Ihm & Krarti, 2012). Figure 6-19 shows a section through the roof while table 6-17 shows the construction materials for the insulated roof.

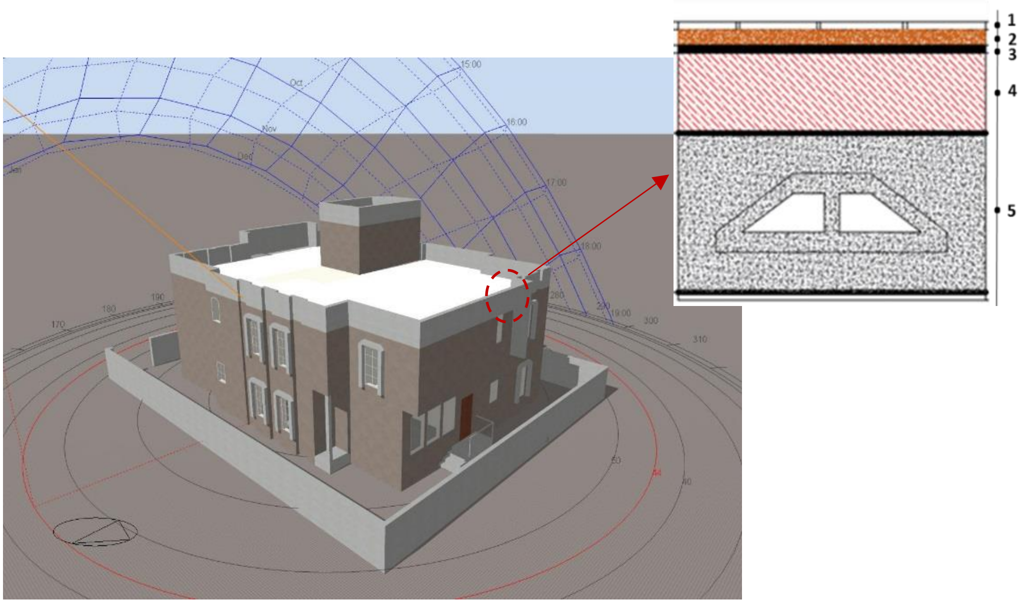


Figure 6-19 a section through the insulated roof

Table 6-17 construction of the insulated roof and total R and U-Value

	Roof insulation	Thickness of layers	R-value(m^2K/W) U-value(W/m^2K)
1 (outer layer)	Ceramic tile	10mm	R-value= 3.320 U-value=0.301
2	Cement mortar	20mm	
3	Asphalt	10mm	
4	Polystyrene (insulation)	100mm	
5	Reinforced concrete slab	200mm	
6 (inner layer)	Cement/plaster/mortar-Gypsum plaster	10mm	

The simulation result for the insulated roof using natural ventilation showed 29.03^{0}C for the month of July. The operative temperature compared to the existing building without insulation was 32.18^{0}C. This shows that there is a significant difference between the insulated roof and the uninsulated roof in terms of operative temperature. This seems to confirm existing studies on the importance of insulation in reducing energy demand and improving thermal comfort in buildings. Table 6-18 shows the comparison between the existing building and the improved roof in terms of Operative Temperature.

The simulation of the improved building using AC base on the introduction of insulation indicated 34% in terms of energy consumption compared with the existing building. Table 6-19 shows the simulations results of annual energy consumption for the existing building and the improved roof.

Table 6-18 comparison Operative Temperature between the existing building and the improved roof

Average of Operative Temperature of July (Top)°C - (Natural ventilation)		
Roof	Improved existing case study (Insulated roof)	Existing case study (uninsulated roof)
(Top)°C	29.03	32.18
R-value(m2K/W) U-value(W/m2K)	R-value= 3.320 U-value=0.301	R-value= 0.422 U-value= 2.370

Table 6-19 Annual energy consumption for existing case study and improved roof

Annual energy consumption (kWh) – AC		
Improved existing case study (Insulated roof)	Existing case study (uninsulated roof)	Reduction %
35668.92	54009.83	34%

6.3.1.6 Lighting

The existing building was modelled with incandescent bulbs, which are extensively used in buildings in the study context. The research though it necessary to investigate other alternative bulbs for comparison in terms of energy consumption. Existing literature and initial simulation confirmed that LED bulbs are the best option. Hence, the improved building was modelled with LED bulbs. The normalized power density of the bulb is 2.5 W/m2100lux. The luminaire type is recessed, and the visible fraction is 0.2.

The operative temperature of the improved building using a LED lamp and the existing building using incandescent lamp were 28.62^{0}C and 32.18^{0}C respectively. This confirms that LED lamps are more energy efficient compared to the incandescent lamps. Table 6-20 illustrates comparison Operative Temperature between using an incandescent lamp and LED bulb.

The simulation results of the improved building showed 44% savings in terms of energy demand compared with the existing building. Table 6-21 shows the simulation results of annual energy consumption for both buildings

Table 6-20 comparison Operative Temperature between using an incandescent lamp and LED bulb

Average of Operative Temperature of July (Top)°C - (Natural ventilation)	
Improved existing case study (LED Lamp)	**Existing case study (Incandescent Lamp)**
28.62	32.18

Table 6-21 Annual energy consumption for using an incandescent lamp and LED bulb

Annual energy consumption (kWh) – AC		
Improved existing case study (LED Lamp)	**Existing case study (Incandescent Lamp)**	**Reduction %**
30221.85	54009.83	44%

6.3.2 The simulation results of the improved case study

The simulation results of the improved building based on the different parameters investigated revealed a significant difference compared with the existing building. The results showed that the major saving is due to improvement in the lighting type of 44%. This is followed by roof and wall insulation of 34% and 33.8% respectively. These savings were based on the improvement made on existing building and the simulation results during the summer period in terms of operative temperature. The operative temperatures were compared for all the summer months based on individual parameters and the differences were determined. Table **6-22** shows annual operative temperature and fuel total of existing case study while Table **6-23** shows a comparison between improved parameters with new specifications in terms of annual operative temperature and fuel total.

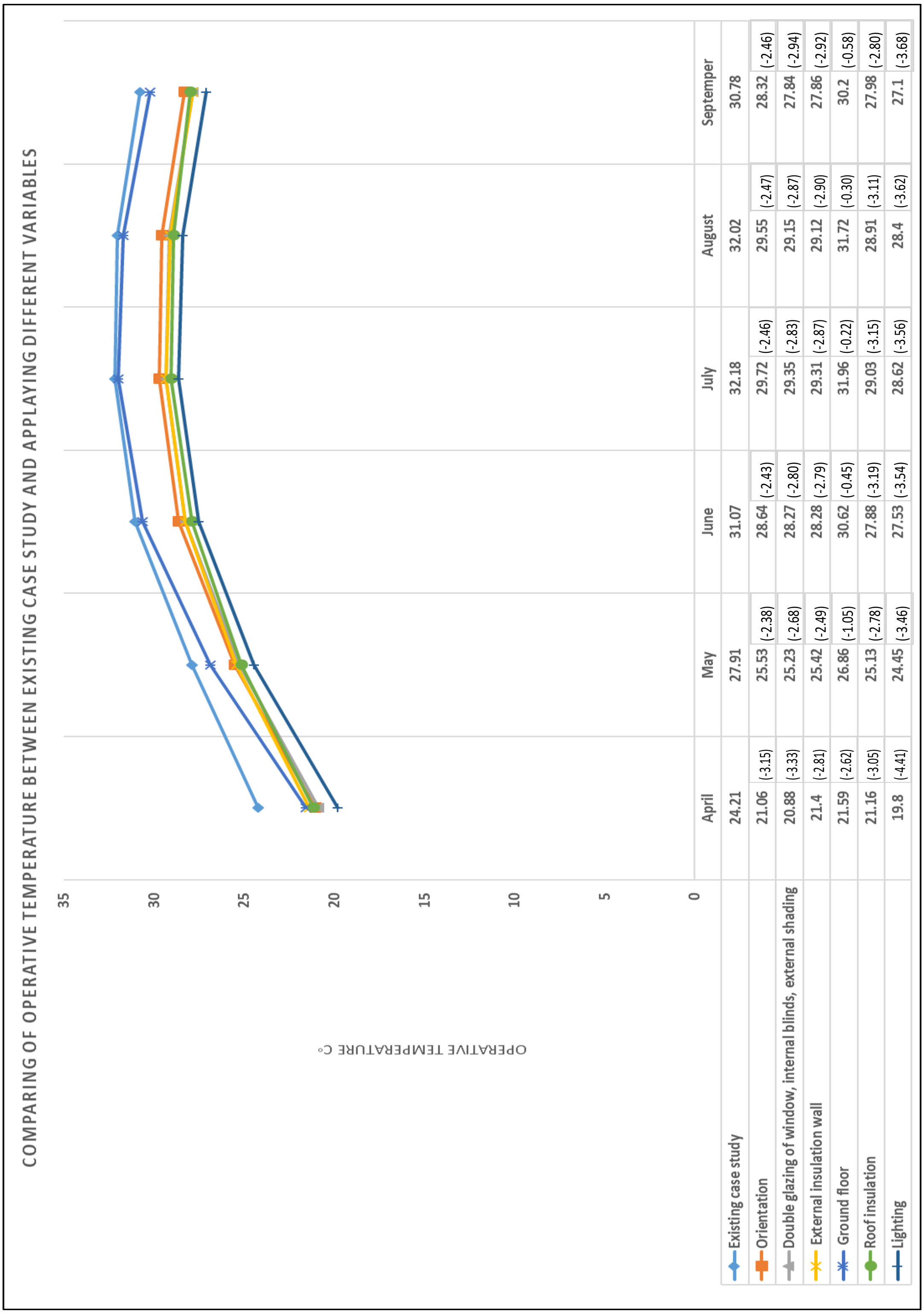
Table 6-22 annual operative temperature and fuel total of existing case study

Annual results	Comfort (Operative temperature °C)	Fuel totals (kWh)
Existing case study WITH (A.C.) OFF	27.19	24977.79
Existing case study WITH (A.C.) ON	25.23	54009.83

Table 6-23 comparison between improved parameters with new specifications and existing case study

An improved existing case study with different parameters		Comfort (Average annual Operative temperature ◦C)	Fuel totals (kWh)/year	New Specification for an improved case study	Specification for existing case study
		(A.C.) OFF	(A.C.) ON		
Orientation		27.16	54000.95	90 ◦E	10 ◦NW
Window					
	Double glazing of the window	27.12	53934.11	Double glazing 6mm/6mm	Single glazing 6mm
	Double glazing of the window, internal blinds	27.07	43091.88	Double glazing 6mm/6mm, internal blinds	Single glazing 6mm
Shading	Double glazing of the window, internal blinds, external shading	26.98	42735.5	Double glazing 6mm/6mm, internal blinds, external shading (overhang + side fins (0.5m))	Single glazing 6mm
Building envelope					
	1- External cavity wall	27.11	51954.14	R-value(m2-k/w) = 0.965 U-value(W/m2-K) = 1.036	R-value(m2-k/w) = 0.483 U-value(W/m2-K) = 2.071
	2- External wall with insulation	27.12	35775.39	R-value(m2-k/w) = 3.073 U-value(W/m2-K) = 0.325	R-value(m2-k/w) = 0.483 U-value(W/m2-K) = 2.072
	3- Ground floor	28.85	47985.09	R-value(m2-k/w) = 1.646 U-value(W/m2-K) = 0.608	R-value(m2-k/w) = 0.613 U-value(W/m2-K) = 1.632
	4- Roof insulation	26.93	35668.92	R-value(m2-k/w) =3.320 U-value(W/m2-K) = 0.301	R-value(m2-k/w) =0.422 U-value(W/m2-K) = 2.370
Lighting		26.03	30221.85	LED	Incandescent

Figure 6-20 sows the operative temperature in summer and the differences in terms of individual parameters compared with an existing case study. This result shows the importance of lighting type and insulation on energy demand and thermal comfort in buildings in the study context. Figure 6-21 shows the summary of the savings.



	April	May	June	July	August	Septemper
Existing case study	24.21	27.91	31.07	32.18	32.02	30.78
Orientation	21.06 (-3.15)	25.53 (-2.38)	28.64 (-2.43)	29.72 (-2.46)	29.55 (-2.47)	28.32 (-2.46)
Double glazing of window, internal blinds, external shading	20.88 (-3.33)	25.23 (-2.68)	28.27 (-2.80)	29.35 (-2.83)	29.15 (-2.87)	27.84 (-2.94)
External insulation wall	21.4 (-2.81)	25.42 (-2.49)	28.28 (-2.79)	29.31 (-2.87)	29.12 (-2.90)	27.86 (-2.92)
Ground floor	21.59 (-2.62)	26.86 (-1.05)	30.62 (-0.45)	31.96 (-0.22)	31.72 (-0.30)	30.2 (-0.58)
Roof insulation	21.16 (-3.05)	25.13 (-2.78)	27.88 (-3.19)	29.03 (-3.15)	28.91 (-3.11)	27.98 (-2.80)
Lighting	19.8 (-4.41)	24.45 (-3.46)	27.53 (-3.54)	28.62 (-3.56)	28.4 (-3.62)	27.1 (-3.68)

Figure 6-20 the operative temperature in summer and the differences in terms of individual parameters compared with an existing case study

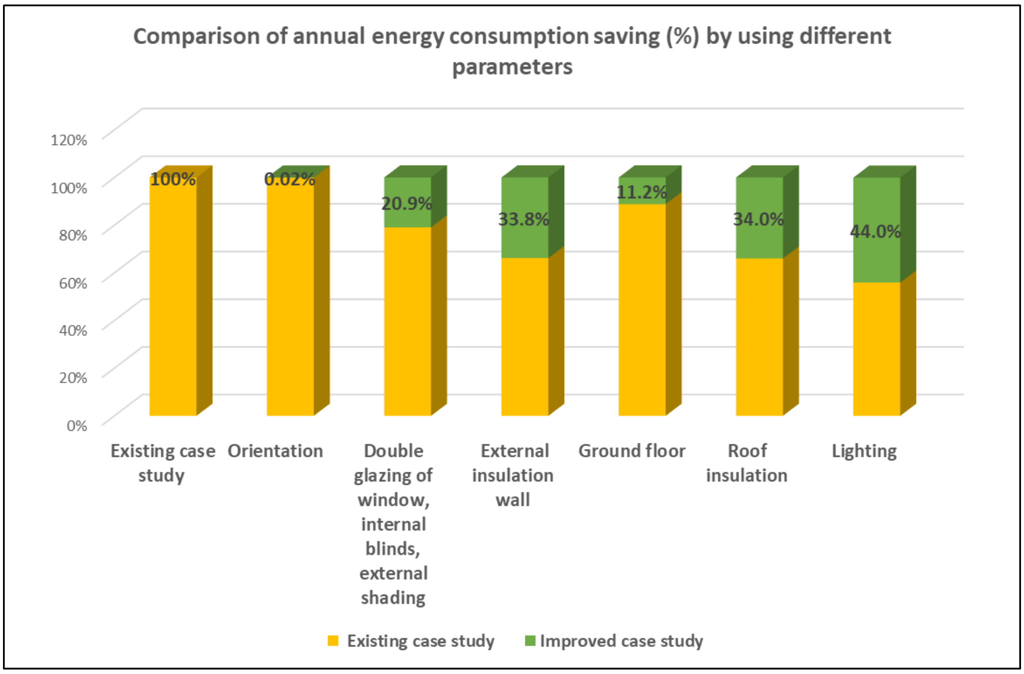


Figure 6-21 the summary of the savings in terms of each individual parameter and existing case study

6.3.3 Comparison between the simulation results of an existing and improved case study in terms of all parameters.

Both the existing and improved case study were simulated using natural ventilation and mechanical cooling systems in terms of all parameters to determine the entire savings regarding operative temperature and energy demand. The simulation results showed a total saving of nearly 16% in July in terms of operative temperature. This corresponds with about 5^0C reduction in operative temperature. The savings in terms of operative temperature for all the summer months were very close. The simulation result shows noticeable improvement regarding indoor thermal comfort, which will definitely lead to a significant reduction in energy demand. Figure **6-22** shows the comparison of the operative temperature between the existing and improved case study in terms of all the parameters using natural ventilation.

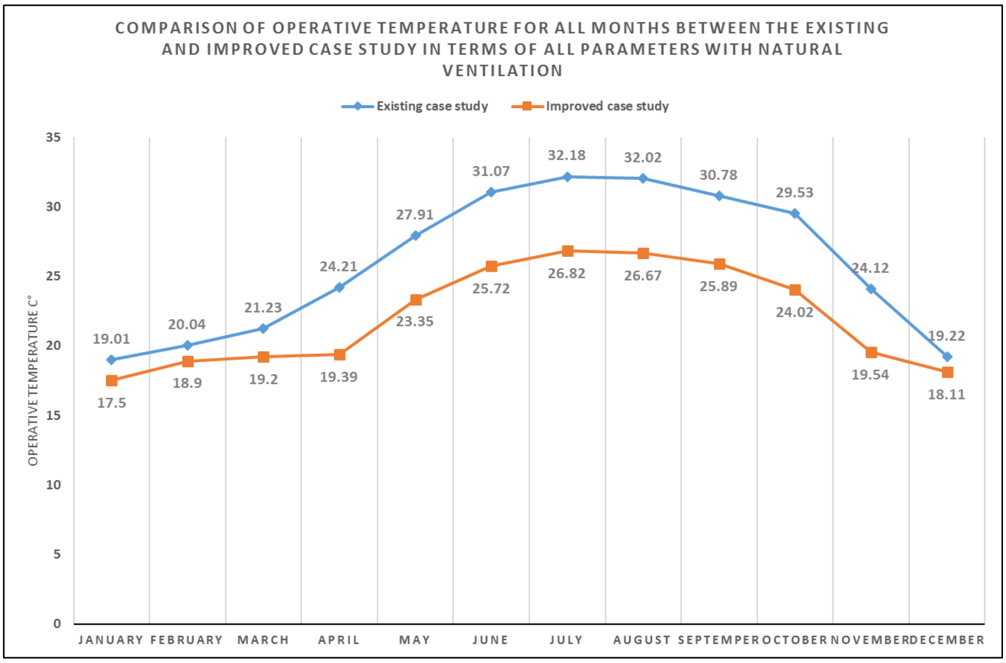


Figure 6-22 the comparison of the operative temperature between the existing and improved case study in terms of all the parameters using natural ventilation

The simulation results for energy consumption of the existing and improved case study were also compared in terms of all parameters using mechanical cooling systems. The simulation results showed 84% savings for all parameters in terms of energy demand. This shows a very significant reduction in energy demand, which can lead to several advantages for building occupants. Figure **6-23** shows the simulation results between the two buildings.

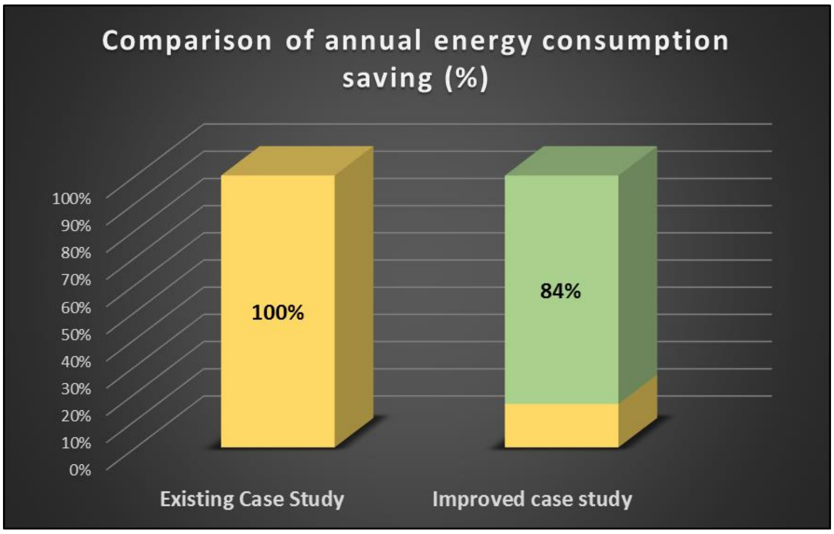


Figure 6-23 the comparison of the annual saving between the existing and improved case study in terms of all the parameters

6.4 Chapter Conclusion

This chapter presented the case study of an existing villa in Benghazi highlighting some information, which includes the location, plot size, total floor area of building and occupancy and energy bills per month. The case study was modelled and simulated using both natural ventilation and mechanical cooling in DesignBuilder. The comfort set point for simulation was based on the adaptive comfort model using the ASHRAE standard. All inputs for the modelling of the case study were based on building construction details and material specification obtained from field survey, measurements and observation.

The simulation results using natural ventilation using both natural ventilation and mechanical cooling systems revealed important information about residential buildings in the study context. The orientation of the case study building was against the recommendation that the long axis of buildings should face the north-south axis to minimise heat gain and improve thermal comfort in hot climates (Elaiab, 2014). The total average daylight factor, the total minimum daylight factor and the total floor above threshold in square meter are 22.1%, 0.89%, and 26.536m^2 respectively. Hence, no functional space in the case study building met the minimum daylight factor of 2%. This shows the need to improve daylighting in existing buildings.

The simulation results using natural ventilation shows that people will be comfortable from the month of October to April in their dwellings. The results also indicated thermal discomfort in a dwelling from the months of May to September. The lowest and the highest operative temperature were 27.91^{0}C and 32.18^{0}C in May and July respectively. The total annual energy consumption using natural ventilation was 24, 977.79kWh while the major energy consumption for the dwelling was for artificial lighting at 21407.56 kWh.

The simulation results using mechanical cooling systems, split unit ACs revealed the lowest operative temperature in the month of April at 22.22^{0}C while the highest operative temperature was for July at 26.48^{0}C. The total energy consumption using mechanical cooling was 54,009.83kWh. This is almost twice the energy consumption in the building using only natural ventilation. The highest energy consumption for the case study building was due to cooling load at 32143.38kWh. This means the total energy consumption for space cooling in kWh/m^2 per year was 72, which is higher than the European Standard recommendation of 20-30kWh/m2 per (Carmody et al., 2009).

HVAC template revealed that it is difficult for building occupants to be comfortable using natural ventilation only. Moreover, the simulation results show a high level of energy consumption due majorly to excessive use of artificial lighting even during the day.

The simulation results using mechanical cooling (split ACs) helped to achieve comfort in buildings, especially in summer but with high-energy demand and CO_2 emission nearly double the consumption using natural ventilation.

This chapter also documents the conducted on the case study building. The improvement measures which were mainly passive covered orientation, windows, external walls, ground floor slab, roof, and lighting. The improvement measures led to savings in terms of operative temperature and energy consumption. The savings in terms of operative temperature for all the summer months were very close. The total savings in July in terms of operative temperature was nearly 16%, which corresponds to about 5^0C reduction in operative temperature. The simulation results showed 84% savings for all parameters in terms of energy demand. The total savings in terms of operative temperature and energy construction showed a significant reduction in energy demand, which can lead to several advantages for building occupants.

The results from the simulation of the case study and the improved case study confirmed the need to improve the approach to the design of residential buildings in Benghazi. Moreover, it revealed the relevance of passive design approaches to achieving energy efficiency in buildings, which has been adopted for this study.

7.0CHAPTER SEVEN: A FRAMEWORK FOR DESIGN OF DWELLINGS IN HOT CLIMATES

7.1 Introduction

The main objective of this research is to produce a framework for designing energy efficient dwellings satisfying socio-cultural needs in hot climates. This chapter presents an overview of the framework, the development of the proposed framework and discussions on the three major stages involved. Furthermore, this chapter documents the application of the proposed framework through the design of a prototype courtyard house. Section 7.2 presents a brief overview of the framework involving theoretical and conceptual frameworks while section 7.3 outlines how the proposed framework was developed. It was necessary to explain the stages involved in the framework. Hence, section 7.4 discussed the three stages of the framework, which are data collection and analysis, design principles and considerations and building design and evaluation. Section 7.5 presents the proposed prototype courtyard design, which was developed based on all the research findings from the literature review, field investigation, and case study of an existing villa using dynamic thermal simulation. The chapter summary in section 7.6 concludes this chapter.

7.2 Overview of the Framework

Rouse (2015) defined a framework as a structure that aims to provide guidance for developing a system into a meaningful and useful resource that is more elaborate than protocol and more prescriptive compared to the structure. Clear (2016) considered framework as a form of a checklist which can serve as a bioclimatic tool for designing more comfortable and energy efficient homes. Previous studies have revealed that there are two types of framework, theoretical and conceptual frameworks. According to Camp (2001), a theoretical framework referred to explanations about phenomenon while the conceptual framework is a structure of what has been studied so as to provide the best explanation relating to the natural progression of the phenomenon being studied. Merriam (2001) posited that theoretical framework provides the researcher the way to view to the world. Conceptual framework, on the other hand, is “a network, or a plane of interlinked concepts that together provide a comprehensive understanding of a phenomenon or phenomena” (Jabareen, 2009, p.51). He added that conceptual framework is determinist and so the outcome cannot be predicted. Mile and Huberman (1994, p.440) study stated that a conceptual framework “lays out the factors, constructs, or variables, and presumes relationships among them”. The development of a theoretical or conceptual framework could form the main objective of a research (Green, 2014). This is in line with the goal of this study, which aims to produce a framework for designing energy efficient dwelling satisfying socio-cultural needs in hot climates. Based on this overview, the researcher is of the view that the proposed framework which is the outcome of this research is a conceptual framework.

7.3 The framework development

The proposed framework was produced according to the process which was identified through the research method adopted in this study for achieving the design of energy efficient buildings. The design of the framework was informed mainly by the interviews conducted with 12 design professionals and the interview questionnaire with 72 householders in the study area. Hence, it captures the views of both designers and building occupants who are very relevant to the design of buildings. An important design principle considered was the provision of the courtyard in the design of buildings to improve privacy for the building occupants and thermal comfort and reduce energy consumption. The design of the framework was also influenced by a simulation study of the existing building, which revealed important design principles, and building construction and material specifications for energy-efficient buildings. The framework is divided into three major stages. These will be discussed in the next section.

7.4 The Proposed Framework

The proposed framework is subdivided into three stages namely data collection and analysis, design principles and considerations and building design and evaluation. These stages are expected to lead to an output, which is the proposed energy efficient dwelling for hot climates. The framework has been produced, which for general applications for dwellings in hot climates. The stage three in the proposed framework reflects the building design to meet local community need as a first and the main item. Figure **7-1** shows the proposed framework.

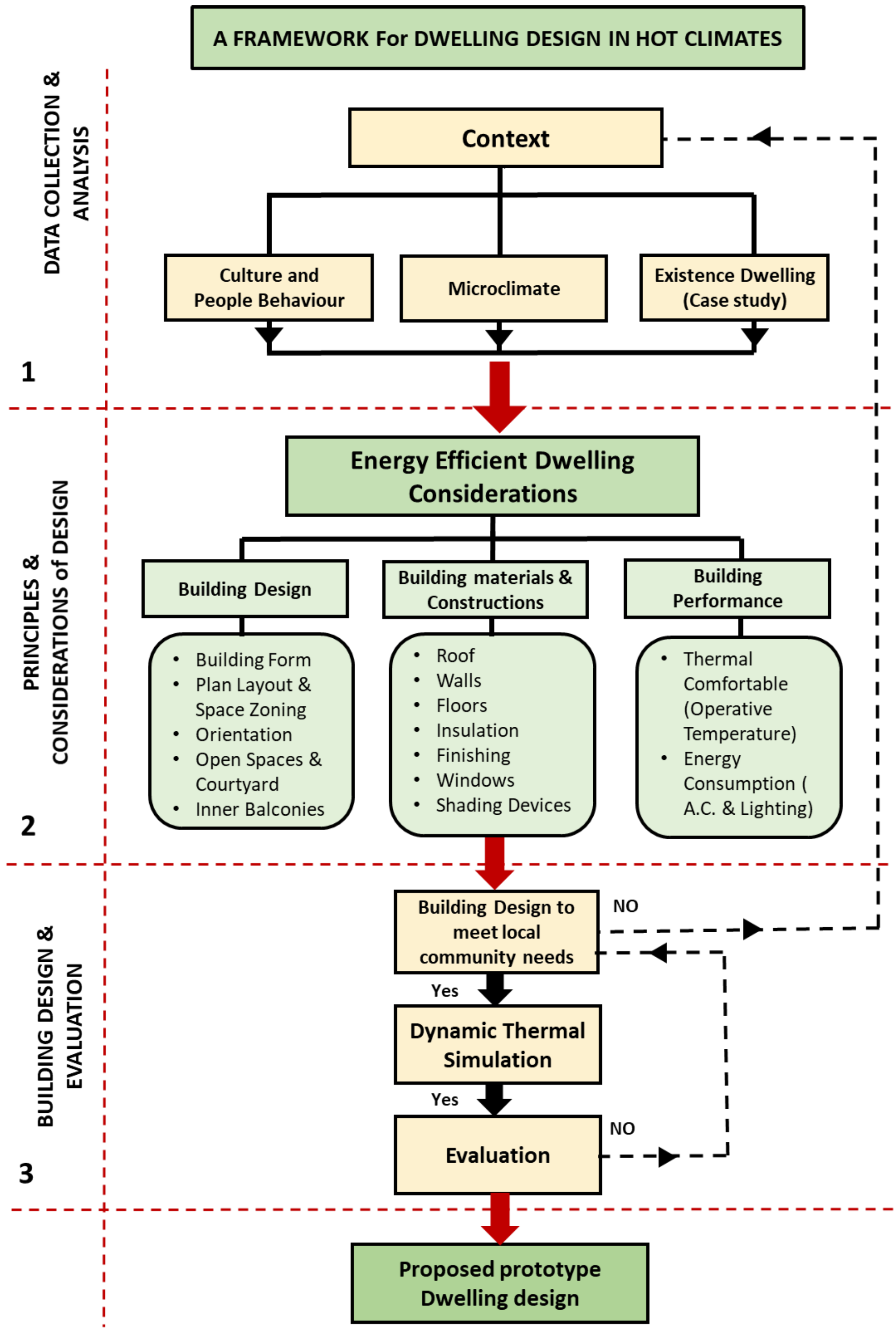


Figure 7-1 the proposed framework of the research

7.4.1 Stage One: Data collection and analysis

To produce a design for a particular location, it is important to understand the context in terms of the culture and the needs of people, the microclimate and information about existing buildings. A combination of observation and questionnaire survey was used to gather data on these subjects from meetings with householders. In addition to the previous literature on the climate of Benghazi, the researcher conducted physical measurements of climatic data to determine the operative temperature and for comparison with existing data. A detailed case study of an existing villa was carried out to provide data on typical existing dwelling types. Contextual data and their analysis were presented in chapter 5.

7.4.2 Stage Two: Design Principles and Considerations

This stage of the framework deals with design factors for energy efficient dwelling in hot climates. It centered on building design, materials, construction, and performance. The research findings revealed suggested building design and construction specifications for energy efficient design and thermal comfort in hot climates. The next section documents these and some relevant design approaches.

7.4.2.1 Building design

a. Building form

It has been discussed earlier in this study that building form can have a significant impact on energy demand in buildings. This can be found in chapter 2, section 2.5.2. In hot climates, the major challenge is to reduce cooling load in buildings. Hence, the focus of building form should be to reduce solar gains by the adoption of shading devices. It has been established in the literature review that building with the small surface area to volume ratio will perform better in hot climates. Therefore, it is necessary to minimise surface area to volume ration in such climates.

The survey of existing buildings in Benghazi, the study context revealed that the surface area to volume of buildings are too large and this can contribute to thermal discomfort and energy consumption. Other strategies in terms of building form towards achieving energy efficiency building are as follows:

- The ratio of height to width of courtyard should be nearly 1:1 to increase the area of shading. The courtyard form will enhance privacy; provide a play area for children, sitting area and other family activities.
- Rectangular building form with the shortest side facing east is the best orientation for hot climates. The interview with design professionals in the study context confirms this.
- Designers should try to minimise long flat external surfaces and encourage recessed and protruding external surfaces to improve shading and minimise solar gain.
- Local architectural forms that are energy efficient and can improve thermal comfort should be adopted.
- To minimise incident solar radiation, encourage self-shading form in the design of buildings.

b. Plan layout and space zoning

Plan layout and space zone are important factors for the design of buildings. The layout and zoning of spaces can determine the level of privacy and thermal comfort in those spaces. For instance, if a bedroom is zoned to the western side, it will be affected by the sun around evening due to high solar gain and can have a significant effect on the use of the space. The layout of residential spaces should consider the level of privacy required between male and female family members and guests. The following points are suggested considering a review of the literature and the research data.

- Nearly square plan layout will enhance the distribution of daylight in buildings.
- Open plan design is important for improving natural ventilation and daylighting in buildings. However, some of the building occupants surveyed whose house plan were based on this concept were not satisfied with their buildings. Some of the reasons given were that it is difficult to cool a particular space and spaces are connected and unsatisfactory level of privacy.
- The appropriate level of privacy between male and female should be provided in the design of houses, especially between family members and visitors or guests.

- Majority of the householders' survey preferred four-bedroom house, three bedrooms for children and a bedroom for parents.

c. **Orientation**

The importance of orientation in the design of the building has been discussed in chapter two of this study. Givoni (1998) stated that the major aim of building orientation in hot climates is to reduce heat gain and enhance ventilation in buildings. To minimise solar gains, the majority of windows should be placed on the north and south facades. Moreover, the design should encourage the concept space zoning discussed earlier. Spaces that are expected to be used during the day should be zoned away from the effect of the sun. Bedrooms which are mostly used at night can be placed on the eastern.

d. **Open spaces and courtyard**

Although the benefits of courtyard design in hot arid climates are minimal according to some studies (Yasa and Ok, 2014) and the research findings, the courtyard is very important in the study context for improving privacy and family cohesion. These benefits seem to support Bhavan, (2013) study, which stated that courtyards are important for improving ventilation and have cultural benefits. Other benefits and design principles relating to the courtyard as summarized below.

- Three types of the courtyard (central, corner and side) were investigated in this study. The findings showed that householders preferred side courtyard. Householders not like the central courtyard, which is the oldest form of a courtyard. They have argued that it is old fashion and no longer in vogue.
- To improve the cooling effect of the courtyard, it is important to cover it with a pergola, which can be manually or mechanically operated.
- Water fountain and vegetation should be incorporated into courtyards to improve cooling around the courtyard and indoor spaces.
- The findings from a survey of householders revealed courtyard should be located close to semi-private (living room) and private (bedrooms) areas in buildings.

e. Inner balconies

Householders preferred inner balcony to external balconies. Inner balconies refer to those balconies that overlook the inner courtyard. They always are hidden away from neighbours and the building façade facing the street. Hence, they help to improve privacy and encourage the use of balconies in residential buildings. Energy is saved in buildings during the period that these balconies are used by building occupants. External balconies are those that are exposed to neighbours and passers-by on the street. Most building users in the study context have abandoned or converted this type of balcony other uses because they felt it does not provide the required level of privacy. Figure – and figure – shows inner and external balconies respectively. The following are other design principles regarding balconies.

- It is important for inner balconies to be attached to private areas around inner courtyards.
- To ensure safety of both children and adult, the height of balustrades should not be less than 900mm and must be constructed with durable materials.
- The balcony should wide enough for easy circulation.

7.4.2.2 Building materials and constructions

The importance of building materials and construction on comfort and energy consumption in buildings have been discussed in this study in chapter 2, section 2.5.4. This section presents the summary of findings from the literature review and primary research data. This is presented under roof, walls, floors, windows and shading devices.

a. Roof

Previous studies have revealed that roof insulation and the colour of the roof are important factors in terms of comfort and energy demand in hot climates. All roofs in residential buildings in the study context are a flat roof. The research findings regarding roof in buildings are summarized below.

- The insulation material should be placed on the external side of the roof and properly protected by waterproofing (ECBC, 2007).

- The thickness of the insulation material is key to its performance. A study by Halwatura and Jayasinghe (2008) shows that the higher the thickness of the insulation material, the better the energy performance.
- Properly insulated materials with low U-value are the most appropriate to reduce the effect of solar radiation in hot climates.
- Cool roofs, which are designed to reflect a significant amount of sunlight in order to improve indoor thermal comfort and reduce energy demand are suitable for hot climates. The previous study has shown that light colour roof can reduce heat gain up to 30% compared to dark colour roofs.

b. Walls

Walls form a major part of the building envelope and it is important in reducing heat gain in buildings. The major wall construction type in the study context is a single leaf, one layer. The one-layer wall is rendered externally with cement mortar and plastered internally with gypsum plaster. Studies have recommended thick; cavity and insulated walls are good alternatives for the single concrete hollow block. Of the three types of wall, insulated is the most appropriate for residential buildings in hot climates. The following should be noted for the design and construction of the wall in hot climates.

- Materials with high thermal mass are recommended for wall construction in hot climates. The wide diurnal range of temperature makes this possible. The survey findings showed that residential buildings in the study context are mostly built without insulation. The researcher recommends insulated walls based on the findings from a simulation study of the existing building and evidence from the literature review.
- Cavity walls are also important for reducing solar gains in buildings, but the simulation study of existing building revealed that there performed below the insulated wall. In terms of cost, cavity walls will be cheaper than insulated walls. Hence, it can be a starting point for those who cannot afford insulated walls.
- It is recommended that light colour paint should be used on external walls to reflect solar radiation thereby reducing solar gains.

- Uninsulated lightweight blocks are recommended for internal partitions since there are not directly exposed to solar radiation.

c. Floors

Raised concrete floor slab is mostly used in the study context. Previous studies have recommended on-ground uninsulated concrete slab as the most suitable for floor construction in hot climates. This is because its contact with the earth makes it absorb heat during the day and release it at a later time to improve thermal comfort in buildings (Chojnacki, 2003; Al-Zubairu, 2007; Abdolmaleki, 2011; Geetha and Velraj, 2012; Iyengar, 2015). The simulation study of an existing building earlier in chapter 6 confirmed this.

d. Windows

Fenestration, especially windows are responsible for the significant amount of heat gain and loss in buildings. Ralegaonkar and Gupta (2010) stated that windows are a significant aspect of the building envelope that can have an obvious effect on energy consumption in buildings. Hence, building materials and construction specifications for windows are key to achieving energy efficiency in buildings. This section presents relevant design principles regarding windows that can be adopted in hot climates towards achieving energy efficiency in buildings. These strategies based on research findings are:

- Window-to-wall-ratio (WWR) for hot arid climates should not exceed 15% (Madilawi, 2012).
- Single glazing clear glass is mostly used in the study context, but previous studies and simulation results of improved case study showed that double glazing, clear glass is more appropriate for the study area.

e. Shading devices

The major challenge with buildings in hot climates is on how to reduce solar gains. Hence, a major target of energy efficient building design is to significantly reduce solar gains through the building envelope. Shading devices have been suggested in previous studies as a means of reducing solar gains and energy demands in buildings. The use of solar shading devices, especially window shading are not common in the study area. Findings from the research data, particularly the simulation study of an existing villa show that local shading can help to reduce solar gains and improve comfort in buildings. Some design strategies for hot climates in terms of shading devices are as follows:

- The effect of shading devices depends on the depth of the overhang and side fins. A study by Wang et al. (2007) shows that an increase in the depth of shading devices between 30cm to 90cm will lead to a corresponding increase in energy savings. Hence, 30cm, 60cm and 90cm lead to 3%, 7% and 10% savings in terms of overhang shading devices. The researcher adopted 50cm overhang deep for the improved case leading to appreciable savings in energy demand.
- For hot climates, it important that shading devices be provided for all the building facades, especially on the east and western facades.
- Encourage the planting of trees on the east and western facades to prevent direct solar radiation on walls and other building elements.
- High reflectance and low absorbance materials are recommended for shading devices to discourage solar gains.

7.4.2.3 Building performance

There are two major factors for the design of energy efficient buildings. These are thermal comfort and energy consumption. The major focus of building performance modelling is also these two factors. Therefore, it is important for design professionals to be familiar with the effect of the choice of materials and construction specification on these factors.

a. Thermal comfort

Thermal comfort is a significant factor in designing energy-efficient buildings. Thermal comfort concept has discussed in chapter two and five in the study. It is difficult to design energy efficient buildings without the knowledge about the comfort temperature in the particular climate. As stated earlier, there are two methods of determining thermal comfort temperature in buildings namely Predictive Mean Vote (PMV) and Adaptive method. The researcher applied these methods to the study context and found that the adaptive method is more suitable for calculating thermal comfort temperature. The operative temperature gotten through the adaptive method approach will be used as the comfort set point for dynamic thermal simulation in DesignBuilder. Therefore, it is important for design professionals to first determine the neutral temperature for building occupants in a chosen climate before designing an energy efficient building.

b. Energy consumption

The goal of energy efficient building design is to achieve thermal comfort in buildings at the lowest possible energy demand. To determine the level of energy demand in buildings, design professionals should have the knowledge of building materials and construction techniques and their implications on energy consumption. This study has investigated different parameters in terms of energy consumption and found that mechanical cooling systems and type of artificial lighting have the highest effect. Nevertheless, a combination of all the strategies, which has been used in this study, will lead to more saving than individual strategy.

7.4.3 Stage Three: Building Design and Evaluation

It has been stated earlier in this study that the design of buildings is a significant factor in reducing energy consumption in buildings. Building evaluation using simulation tools is also an important factor in determining thermal comfort and energy demand in buildings. Hence, this stage of the framework focuses on the design of building bearing in mind the design considerations identified in stage two and dynamic thermal simulation of the proposed design towards satisfying thermal comfort and energy requirements.

After the design of the proposed building is produced, it is evaluated using building simulation and evaluated based on the context in terms of thermal comfort and socio-cultural factors. If these factors are met, the proposed building becomes the acceptable design. If the design fails to meet these factors, it is redesign and re-evaluated until it is satisfactory and then accepted as the proposed energy efficient building design.

7.5 Benghazi framework

The proposed framework has been applied to the study context, which is called the Benghazi framework. The Benghazi framework is specifically meant for Benghazi, the study area. According to the main results from observation, questionnaires, interviews, and simulation, which are the outputs from the first stage with main principles and consideration from the second stage, courtyard concept was found necessary for Benghazi residents.

The difference between the proposed and Benghazi frameworks is in stage 3, building design and evaluation. The Benghazi framework has specific building design to meet local community need as the first item in stage 3, which has designed with courtyard.

Figure **7-2** shows the Benghazi framework which specific to the study context.

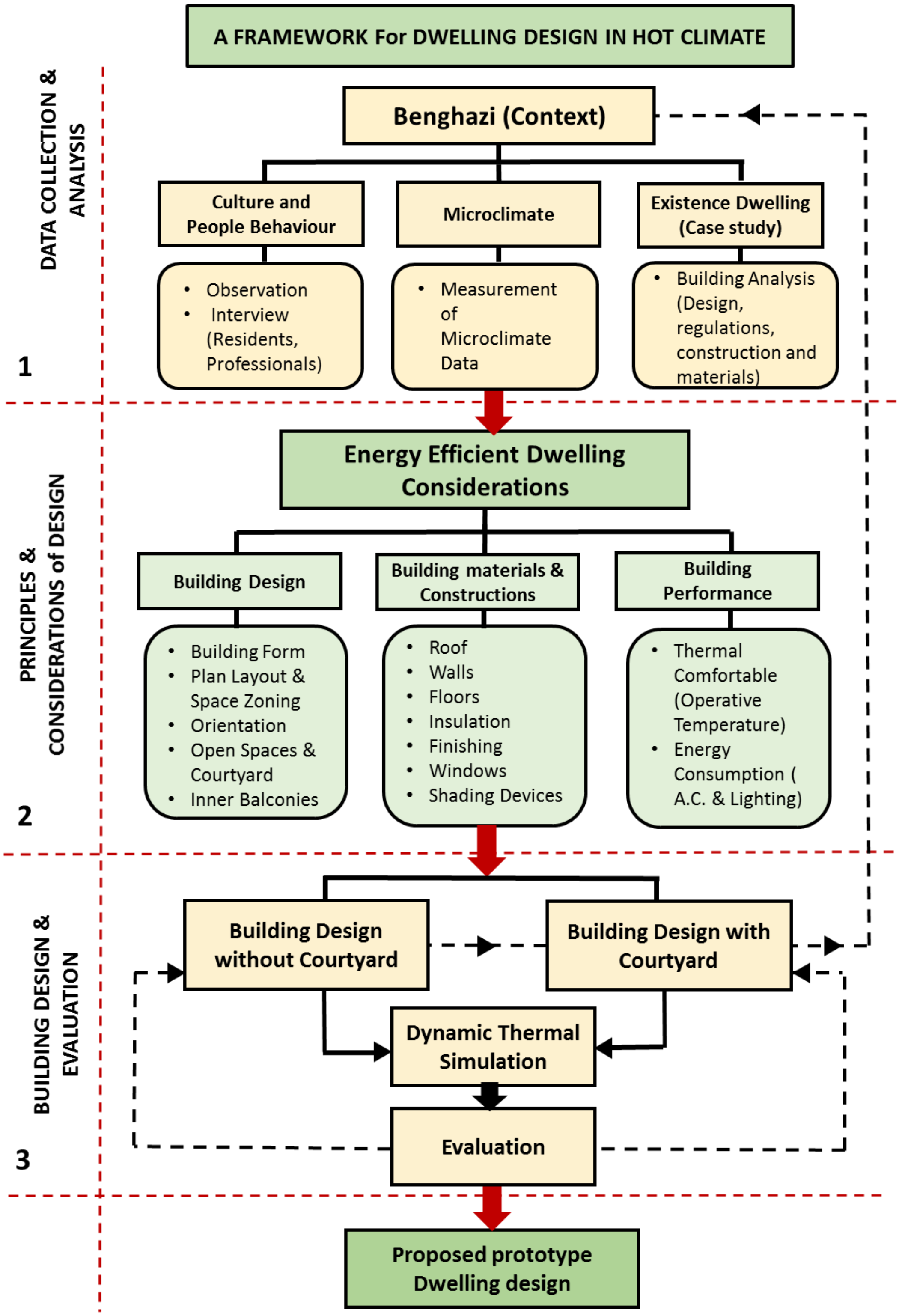


Figure 7-2 the framework of the study context

7.6 Prototype courtyard design

This section corresponds with stage three of the framework, which deals with building design and evaluation. It presents the proposed prototype courtyard design, which has been developed based on all research findings from literature review, field investigation and case study of an existing villa using dynamic thermal simulation. This is to test the proposed framework for design energy efficient dwelling satisfying socio-cultural needs in hot climates. This model has highlighted relevant energy efficiency design strategies including courtyard design, which can serve as solutions that can be applied to individual houses and at the entire urban scale. The proposed model is expected to serve a baseline, which can be adopted by designers to the design of energy efficient residential buildings in hot climates. The previous study emphasized the importance of local conditions involving knowledge and culture in achieving sustainable development (Bruen et al., 2014). Hence, these factors as incorporated in the proposed framework based on the research findings were properly considered in the design of the prototype. The proposed prototype was modelled in Design Builder using the parameters identified from the improved case study. Moreover, the courtyard was added to the design of the prototype to enhance the privacy of building occupants, which is a relevant factor, is the study context. The prototype was simulated, and results compared with the existing building and the improved case study for savings in terms of energy consumption.

7.6.1 Building design concept

According to the literature review, courtyard plays an important role in improving socio-cultural aspects of the people and family cohesion through the provision of privacy. As discussed earlier, the researcher investigated three types of courtyard during the field investigation. These are central, side and corner courtyard designs. The findings showed that 70% of the building occupants preferred the side courtyard design. Hence, this courtyard design concept was adopted for the prototype design. Studies have shown that an appropriate courtyard should have a ratio of width to height of nearly 1:1. This is to improve shading towards enhancing thermal comfort in building interior spaces. The prototype design has a ratio of width to height of 7.1:7.9.

Figure 7-3 shows the 3D modelling of the prototype courtyard design.

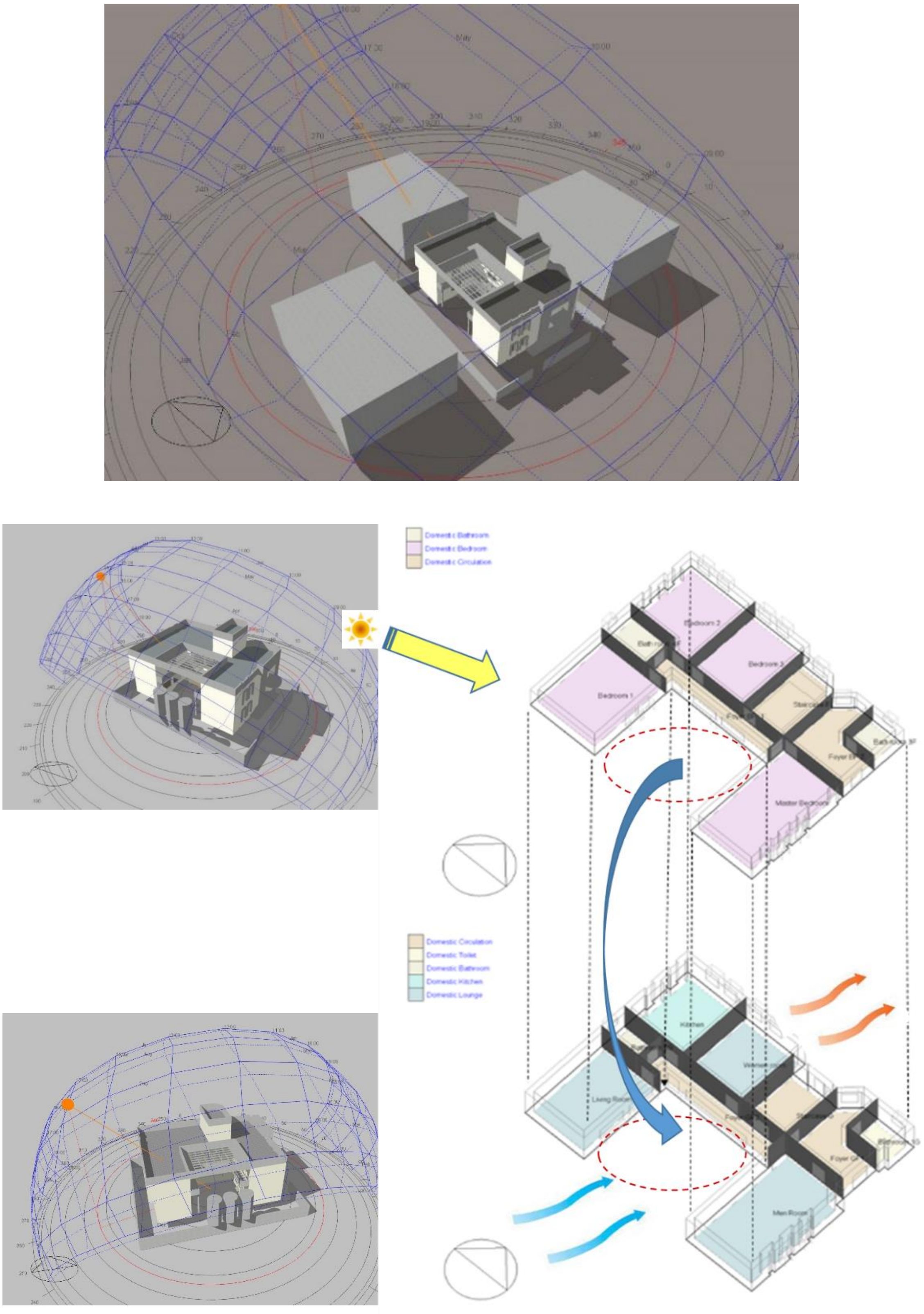


Figure 7-3 the 3D modelling of the prototype courtyard design

7.6.2 Spatial layout of the prototype

The design of the prototype took into consideration the local climate, building occupants preferences, land use policy and other factors. For a plot area of 500m2, people are only allowed to develop 40% and the number of floors should not be more than two. The layout of the floor of the proposed detached villa is divided into semi-public, semi-private and private areas. The ground floor comprises of the semi-public and semi-private areas while the first floor is purely private. Semi-public areas are main entrance, male and female guest rooms and a shared WC. Semi-private areas are staircase, kitchen, living room and bathrooms. The first floor, which is the private area, has four bedrooms and two bathrooms. A bedroom is ensuite while the bathroom is shared by three bedrooms. The first has an inner balcony overlooking the courtyard. The courtyard is completely converted with pergola at the roof level to provide shading for both the inner balcony and the courtyard. Threes were assumed to be planted at the open end of the courtyard to improve the privacy of the building occupants and provide shading. The courtyard area will serve as relaxation point during summer, play area for children among other uses.

The total ground floor area is 172 m2 excluding the courtyard which has a total area of 60.2 m2. The total floor area of the building is equal to 34.4%, which complies with the government requirement of 40%. Open spaces around the building can be used as parking spaces and storage areas. Table 7-1 shows relevant building information about the prototype design. Figure 7-4 and Figure 7-5 show the ground floor and the first floor layout of the proposed prototype respectively.

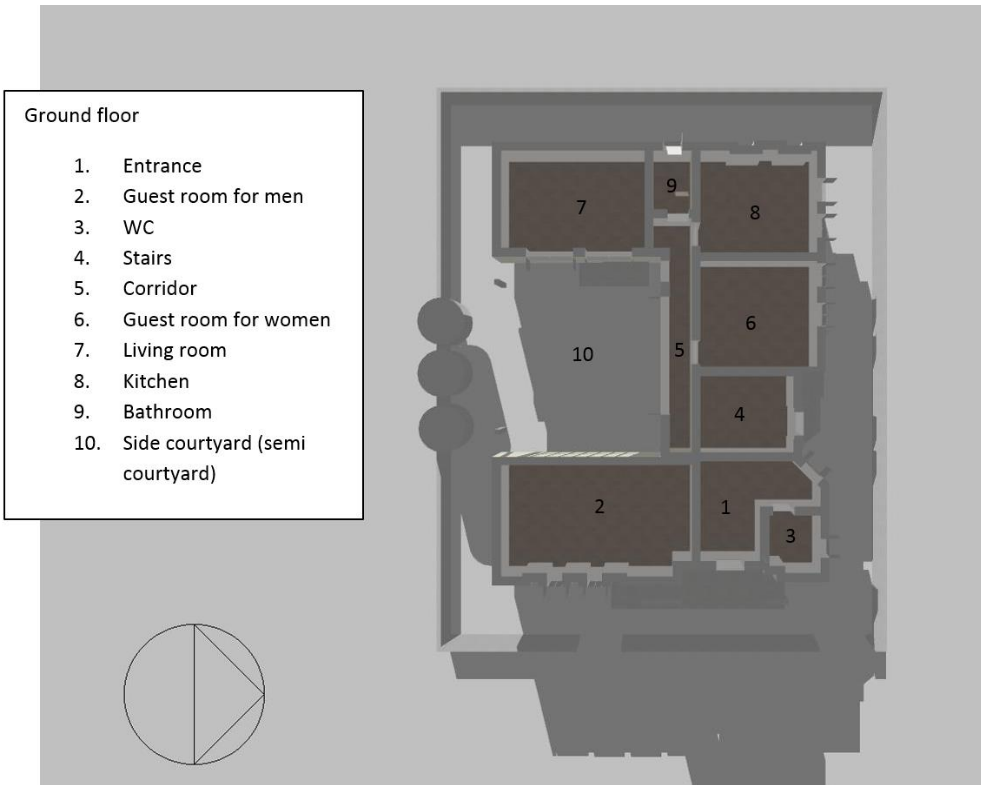


Figure 7-4 the ground floor layout of the proposed prototype

Figure 7-5 the first floor layout of the proposed prototype

Table 7-1 the building information of prototype design

Building Information	
Building orientation	90^0E
Site area	$500m^2$
Total area of building	344m2
Total area of outdoor open space	$267.8m^2$
Total area of courtyard	$60.2m^2$
On- ground concrete floor slab	200mm thick Concrete slab
First floor slab material	200mm thick reinforced Concrete slab
External Insulated wall material	Concrete hollow block
Window type	Casement
Window frame material	PVC
Window glazing	Double glazing clear glass
Glazed area	$80.12m^2$
Building height	8.7m
Roof material	Reinforced concrete slab
Building cooling system	Mix-mode (natural ventilation and AC)
Occupancy density (people/area)	6/510= 0.0118 p/m^2

7.6.3 Modelling of the prototype design

The modelling and simulation of the prototype design were conducted in line with the proposed framework based on the parameters identified under the improved case study. The orientation of the prototype design is 90^0E, which is the best orientation for the improved case study. This section presents the summary of the building information for the prototype design and the construction materials based on the improved case study. This section is discussed under weather data and construction materials. The assumption made for the simulation of the prototype design using natural ventilation and mechanical cooling system are discussed later under section 7.6.4.2 and 7.6.4.3.

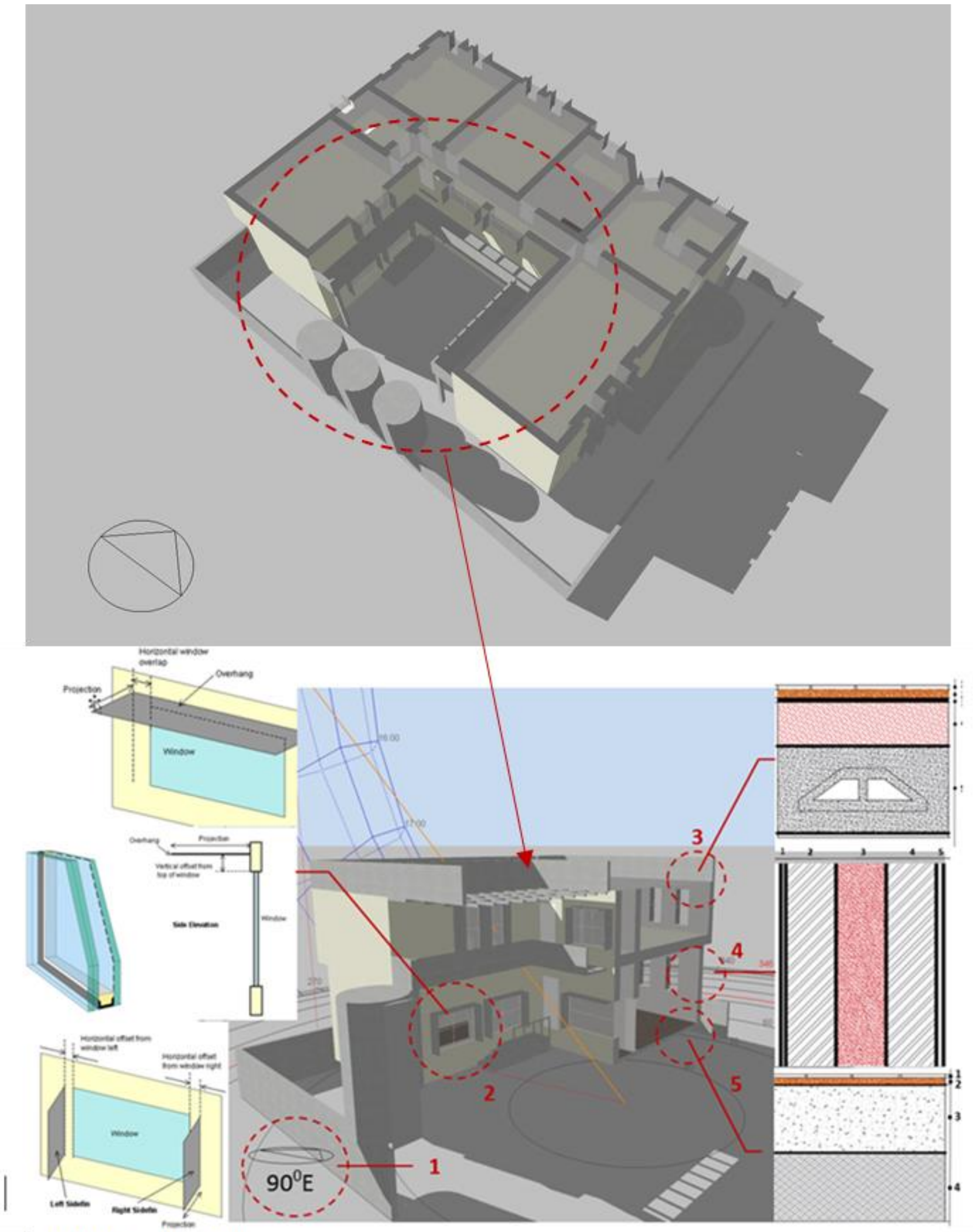
7.6.3.1 Weather data

The typical weather data for Benina international airport in Benghazi was found in DesignBuilder weather files template. The simulation of the prototype design was based on this weather file.

7.6.3.2 Construction materials

The prototype design was modelled in DesignBuilder with the same materials of the improved case study,

Figure 7-6 the prototype courtyard design with all parameters the prototype courtyard design with all parameters. Table 7-2 shows the construction details and U-Values of the various parameters used for the modelling of the prototype design.



Building specifications

(1)	***Orientation 90^0E***
(2)	***Double glazing window with overhang and side fin***
(3)	***Insulated roof***
(4)	***External insulated wall***
(5)	***On-ground floor***

Figure 7-6 the prototype courtyard design with all parameters

Table 7-2 construction details and R and U-Values of the various parameters used for the modelling of the prototype design.

Building element	Material description	Thickness (mm)	R-Value and U-Value
Ground Floor			
	Ceramic porcelain tiles	10	**R-Value** 1.646
	Cement mortar	20	
	Concrete slab	200	**U-Value** 0.608
	Compacted earth filling	200	
Walls			
	Cement/mortar render	10	**R-Value** 3.073
	Concrete hollow block	100	
	Polystyrene (insulation)	100	**U-Value** 0.325
	Concrete hollow block	100	
	Gypsum plaster	15	
Roof			
	Ceramic Tiles	10	**R-Value** 3.320
	Cement mortar	20	
	Asphalt	10	
	Polystyrene (insulation)	100	**U-Value** 0.301
	Reinforced concrete slab	200	
	Cement/plaster/mortar-Gypsum plaster	10	

7.6.4 Building simulation results and analysis

This section discusses the simulation of the prototype courtyard design in terms of daylighting, thermal comfort and energy consumption using natural ventilation and mechanical cooling systems.

7.6.4.1 Daylighting analysis

As discussed earlier in this study, daylighting is an important aspect of energy efficient building design. A building that takes a good advantage of natural daylight will improve visual comfort and minimise the use of artificial lighting which can be highly energy intensive. Nevertheless, previous studies have shown that attempt to maximise daylighting can lead to overheating in buildings, especially when adequate shading for windows are not provided.

The entire building was simulated using BREEAM Health and Wellbeing Credit HEA01 standard for its performance. To achieve a pass in terms of BREEAM standard, the building must meet two conditions. These are:

a. 80% of the total floor area has adequate daylight with minimum average daylight factor of 2% at 700mm height working plane using uniform CIE overcast design sky.
b. Minimum uniformity ratio of 0.4 or at least 0.8% minimum point daylight factor.

The simulation result shows that the building did not achieve an appropriate level of daylighting with The window to wall ratio (WWR) is 14.54% and this is lower than the recommended WWR according to literature review, which is 20%. The reason for this may be attributed to the use of window blinds in the study context, which was modelled in DesignBuilder. However, the living room, which is mostly used during the day, satisfied the minimum daylight factor (DF) = 2.06%. Table **7-3** shows the table of eligible zones for daylighting for the whole building. Figure 7-7 shows the map result for the ground floor of the prototype and the map result for the living room.

Table 7-3 the table of eligible zones for daylighting for the whole building

Summary Results	
Total area (m2)	344.165
Total area above threshold (m2)	232.366
% Area above illuminance threshold	9.5
Criterion a) 80% of area adequately daylit	FAIL
Criterion b) Uniformity ratio >= 0.3, min DF = 0.8%	FAIL
BREEAM Health and Wellbeing Credit HEA01 Status	FAIL

Eligible zones for daylighting

Zone	Block	Floor area (m2)	Min DF (%)	Uniformity ratio (Min / Avg)	Average Daylight Factor (%)	Area Adequately Daylit (m2)
FirstFloor:BathRoom4F	First floor	8.776	0.04	0.04	0.9	0.0
FirstFloor:Bedroom2	First floor	28.067	0.11	0.04	2.9	0.0
FirstFloor:Bedroom1	First floor	32.162	0.49	0.06	8.2	0.0
FirstFloor:FoyerBF2	First floor	12.159	0.00	0.00	2.4	0.0
FirstFloor:MasterBedroom	First floor	39.981	0.25	0.06	4.3	0.0
FirstFloor:FoyerBF1	First floor	18.566	0.01	0.00	1.6	0.0
FirstFloor:BathRoom3F	First floor	5.551	0.34	0.06	5.2	0.0
FirstFloor:Bedroom3	First floor	27.244	0.06	0.04	1.5	0.0
GroundFloor:FoyerGR1	Ground floor	16.577	0.01	0.01	1.6	0.0
GroundFloor:Bathroom1G	Ground floor	5.898	0.91	0.19	4.7	5.9
GroundFloor:BathRoom2G	Ground floor	4.781	0.09	0.08	1.1	0.0
GroundFloor:Kitchen	Ground floor	22.549	0.37	0.09	4.1	0.0

GroundFloor:FoyerGR2	Ground floor	12.163	0.00	0.00	1.3	0.0
GroundFloor:WomenRoom	Ground floor	23.691	0.16	0.11	1.5	0.0
GroundFloor:StaircaseG	Ground floor	19.597	0.36	0.05	7.5	0.0
GroundFloor:MenRoom	Ground floor	39.584	0.50	0.09	5.8	0.0
GroundFloor:LivingRoom	Ground floor	26.819	2.06	0.19	11.1	26.8
Total		**344.165**				**32.7**

Zones with data flagged in red in the table above fail on criterion b).

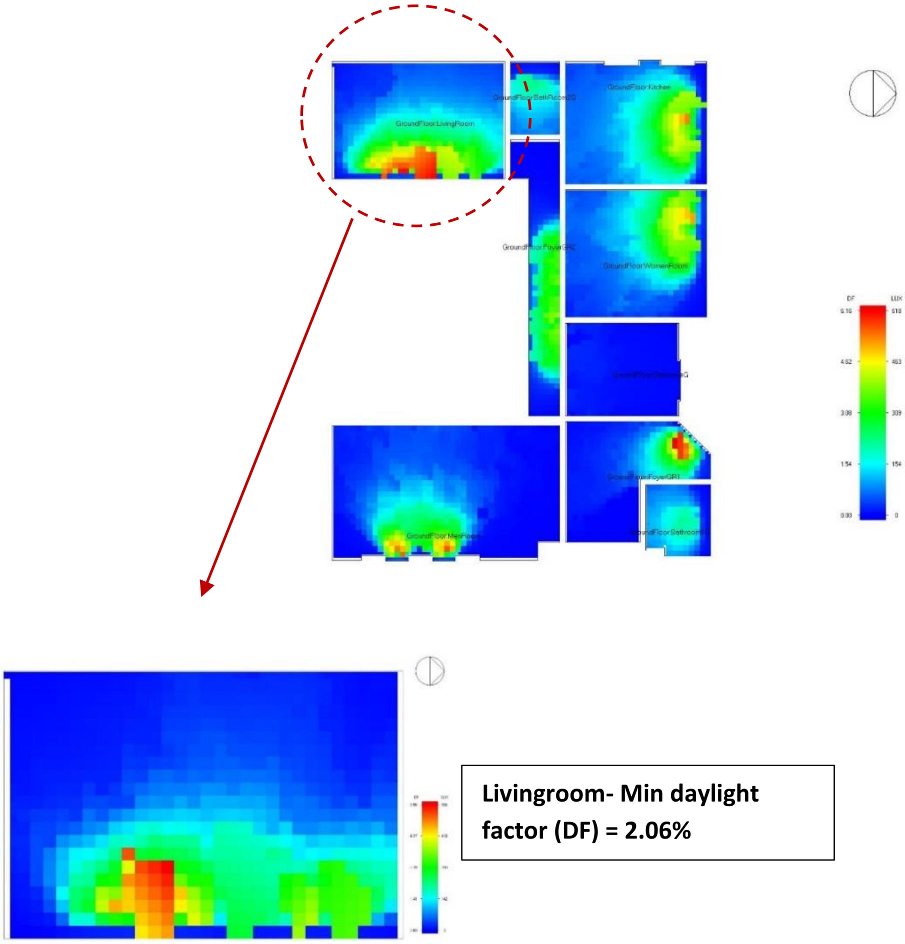
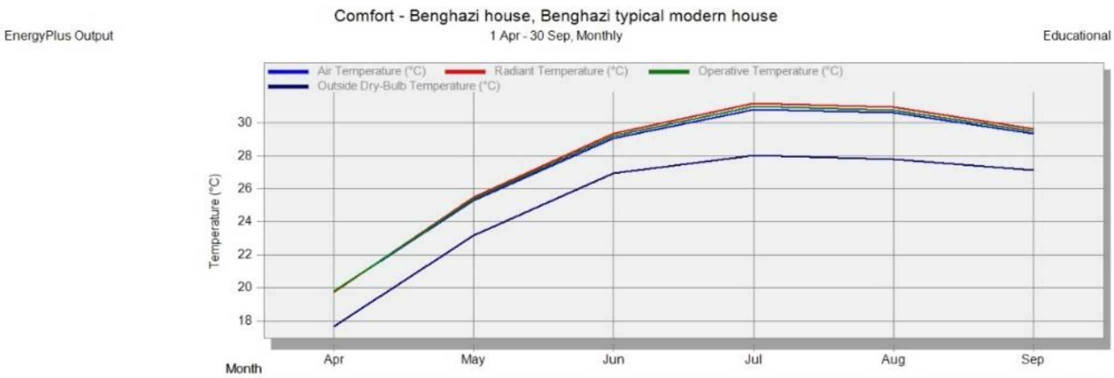


Figure 7-7 the map result for the ground floor of the prototype and the map result for the living room.

7.6.4.2 Energy performance simulation using natural ventilation

some assumptions were made for the simulation of the prototype design using natural ventilation. Air changes per hour (ac/h) of 3 was assumed due to the use of blinds in the study context, which can hinder air movement. Air definition method was by zone and operation schedule was for residential spaces according to the various zones. The windows were assumed to be opened by 100% since the casement window.

The building was first simulated using natural ventilation mode only for summer months. The result revealed that the operative temperature from the months of May to September was above the optimum comfort temperature range of 25^0C - 28^0C despite all the improvement measures. This result indicated the need for the use of mechanical cooling systems in buildings. Moreover, it seems to support the reason for too much dependence on cooling systems in buildings in study context, especially during the summer months. Figure 7-8 shows the simulation results for the summer months using natural ventilation only.



Month	Apr	May	Jun	Jul	Aug	Sep
Air Temperature (°C)	19.76	25.27	29.06	30.79	30.59	29.32
Radiant Temperature (°C)	19.75	25.50	29.34	31.19	30.96	29.61
Operative Temperature (°C)	19.75	25.38	29.20	30.99	30.78	29.47
Outside Dry-Bulb Temperature (°C)	17.65	23.18	26.94	28.04	27.81	27.11
Relative Humidity (%)	51.41	51.17	50.26	45.80	50.64	51.64

Figure 7-8 the simulation results for the summer months using natural ventilation only

- **comparison between existing case study and prototype in terms of operative temperature by using natural ventilation in Living room on 15 of July**

The hottest month in the study context based on the review of existing literature earlier in chapter 2 in July. It has been observed during the survey of existing buildings that temperature different from one room in building to another. Hence, the researcher thought it was necessary to investigate the performance of living for a typical summer day in July. The results for both the prototype and the existing building using natural ventilation only were compared. The results showed a significant difference between the existing building and the prototype design in terms of operative temperature. Figure

7-9 the comparison of operative temperature between existing case study and prototype courtyard design in the living room on 15th of July

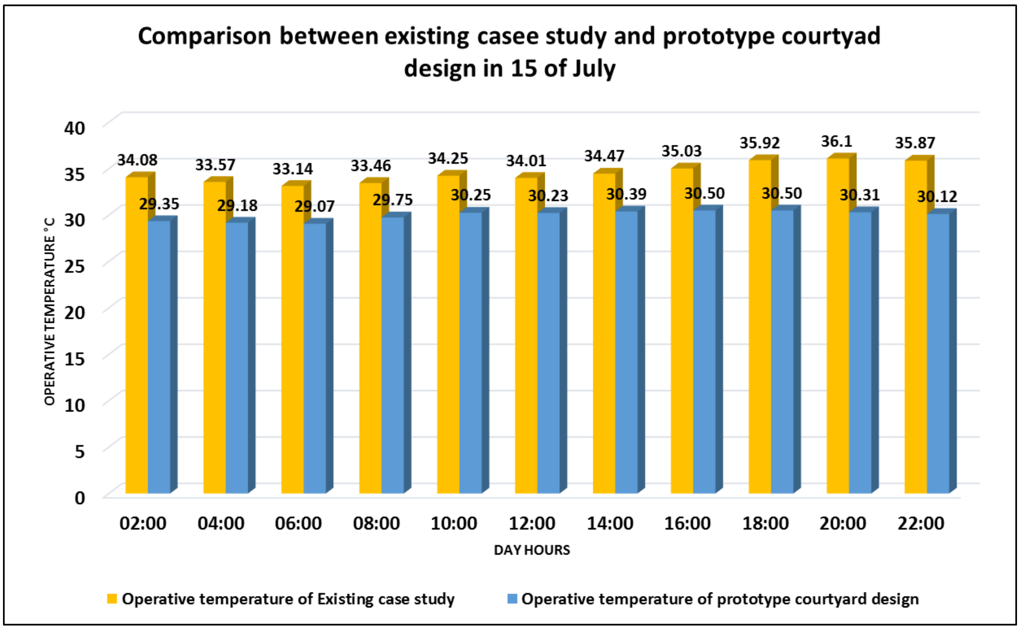


Figure 7-9 the comparison of operative temperature between existing case study and prototype courtyard design in the living room on 15th of July

7.6.4.3 Energy performance simulation using mechanical ventilation

Just like in the simulation of the prototype house using natural ventilation, some assumptions were also made for the simulation of the prototype design using mechanical cooling systems (Split AC). The cooling system coefficient of performance (CoP) was assumed to be 3.5. The minimum supply of air temperature and the humidity ratio of 12^{0}C and 0.008g/g were assumed respectively. The survey of existing villas revealed that ACs are used all the time in buildings during summer months. Hence, the simulation of the prototype design was based on the assumption that ACs were used all the time.

As stated earlier, despite the improvement measures incorporated into the prototype design using energy efficient design strategies and the courtyard approach, the building did not meet the required operative temperature for optimum comfort. Hence, the need to simulate the prototype design in order to achieve the target operative temperature. The simulation results using mechanical cooling system (Split AC) for the summer months met the operative temperature range for the study context of 25^{0}C - 28^{0}C.

Figure 7-10 shows the simulation results of the operative temperature for the summer months using mechanical cooling systems while

Figure 7-11 shows the annual energy consumption using mechanical cooling systems.

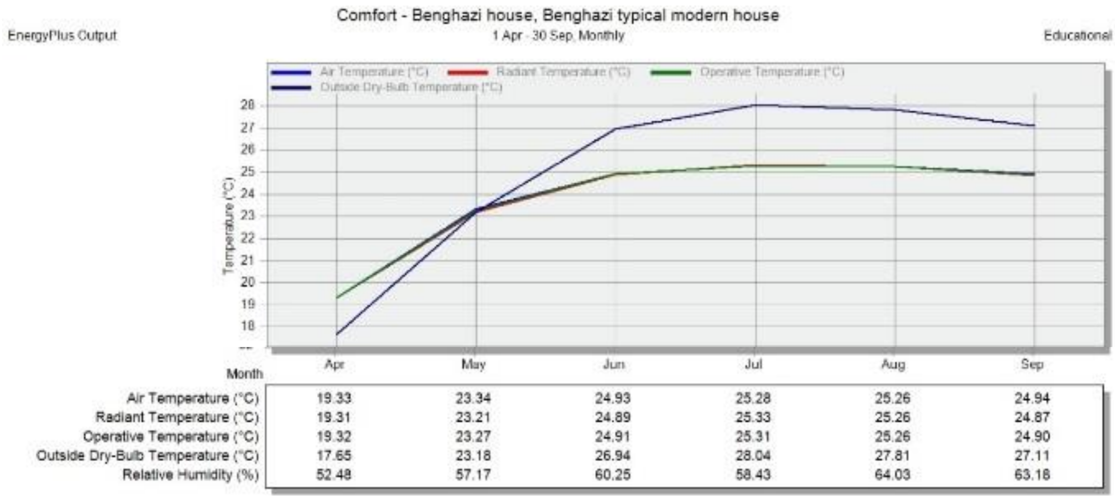


Figure 7-10 the simulation results of the operative temperature for the summer months using mechanical cooling systems

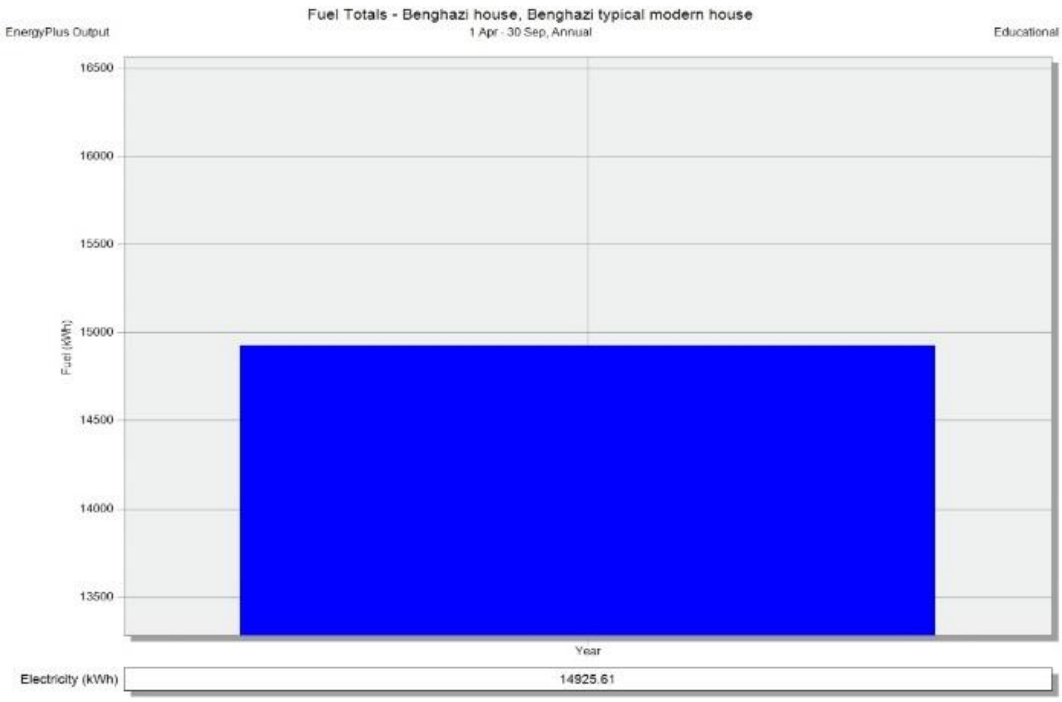


Figure 7-11 the annual energy consumption using mechanical cooling systems

7.6.5 Comparison between existing and improved case study with prototype design in terms of operative temperature using natural ventilation.

The performance of the existing case study, the improved case study, and the prototype courtyard design were compared in terms of operative temperature during the summer period. The improved case study without courtyard has the lowest operative temperature in summer. This is followed by the prototype design while the existing building recorded the highest temperature throughout the summer period. Figure **7-12** shows the comparison between the three buildings in terms of operative temperature.

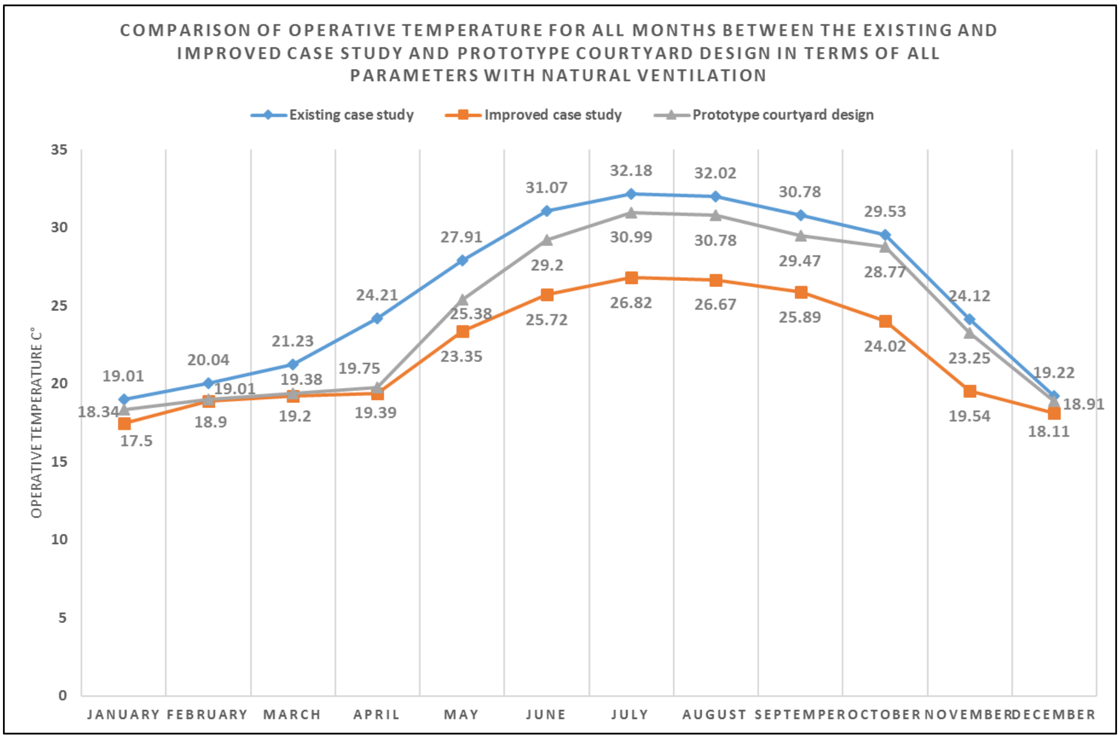


Figure 7-12 Comparison between existing and improved case study with prototype design in terms of operative temperature using natural ventilation

7.6.6 Comparison between existing and improved case study with prototype design in terms of annual energy demand saving.

It was necessary to compare the annual energy demand of the existing case study, the improved case study, and the prototype courtyard design to determine the percentage savings in relation to the existing building. Hence, the performance of the three buildings was compared in terms of their annual energy demand. The improved case study without courtyard performed better with an annual savings of 84% followed by the prototype design, which showed 65% savings in terms of annual energy demand.

However, the prototype design has different floor area. This makes necessary to compare the savings between the three buildings per square meter. Figure **7-13** shows the comparison between the three buildings in terms of the percentage of annual energy saving while Table 7-4 shows the comparison in terms of annual energy consumption per square meter between the three buildings.

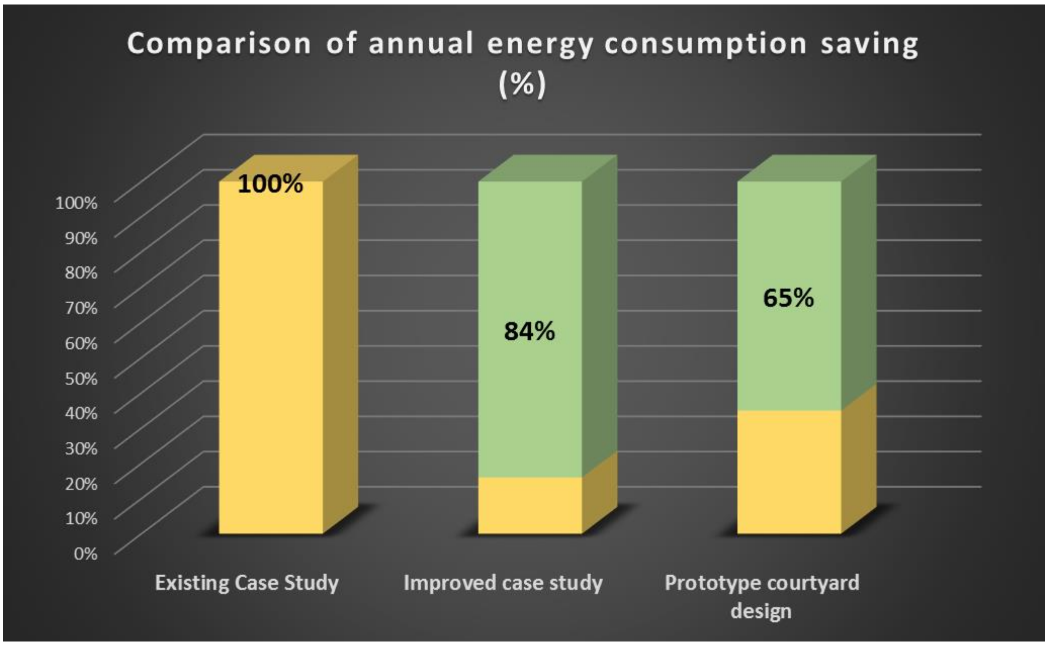


Figure 7-13 the comparison between the three buildings in terms of the percentage of annual energy saving

Table 7-4 the comparison between the three buildings in terms of annual energy consumption per square meter.

	Existing Case Study	Improved case study	Prototype courtyard design
Total area of the house (m2)	441	441	344
Annual energy consumption (kWh)/House	54009.83	8608.57	14925.61
Annual energy consumption (kWh)/m2	122.47	19.52	43.39
Annual energy saving (%) /m2	N/A	84%	65%

7.6.7 Findings from the simulation results of existing building, improved case study and the prototype courtyard design based on natural ventilation.

- Compared with the existing building and the prototype design, the improved case study performed better in terms of both operative temperature and energy demand. This is despite the fact that the total floor area of the improved case study is more than that of the prototype courtyard design. However, the total area of external walls in the improved case study is less than the total area external walls in prototype design which leads to reducing the amount of heat gain through external walls. Moreover, traditional courtyard houses were satisfy comfort requirement by providing privacy because the compactness of the old city help to decrease the effect of sunlight and reduce cooling demands by reducing the area of external walls. Compactness was necessary to minimise high solar radiation through walls in hot climates.
- Despite the improvement recorded for the improved case study and it met the thermal comfort for the case study but it did not meet privacy and other socio-cultural requirements for study context. Whereas, the prototype courtyard design did not satisfy comfort required using natural ventilation but met privacy demand by building occupants and can improve family cohesion among other benefits.
- There is a need for the use of mechanical cooling systems in prototype courtyard design because it did not satisfy comfort requirement for the study context.

7.6.8 Findings from the simulation results of existing building, improved case study and the prototype courtyard design based on mechanical cooling systems.

- The existing building did not achieve the operative temperature range in the study context at comfort set point of 25^0C. however, the improved case study and the prototype design achieved the thermal comfort requirement using mechanical cooling systems at comfort set point of 25^0C.
- The simulation results seem to confirm that mechanical cooling systems are required for thermal comfort in buildings in the study context.

- The savings in terms of energy consumption using energy efficient design principles for the improved case study and prototype courtyard design indicated the importance of energy efficient design in improving thermal comfort and reducing energy demand in buildings.

7.7 Chapter summary

This chapter presented an overview of a framework based on existing literature and discussions on the process that informed the development of the proposed framework. Moreover, this chapter discussed the three major stages of the framework and the proposed courtyard design, which was produced based on the framework.

The proposed framework was produced based on the findings from the research method adopted in this study which aims to encourage the design of energy efficient residential buildings in hot climates, especially in Benghazi, Libya. Hence, the proposed framework captures the opinions of both designers and building occupants.

The three stages of the proposed framework were meant to provide understanding about socio-cultural challenges with the design of houses, the local climate and important data on existing dwellings. Thus, it addressed the culture and behaviour of the people, buildings' microclimate and the study of existing dwellings. The second stage centered on relevant principles and considerations for designing energy-efficient residential buildings. This involves design strategies, building material selection, and construction techniques and determination of building performance in terms of comfort and energy consumption. Important data on these subjects based on the research findings and the literature review in this research were identified and presented in this chapter. The last stage focuses on the actual design of buildings based on the design considerations in stage two. The relevance of building performance modelling was identified in the proposed framework through the incorporation of design evaluation in stage three. Therefore, the proposed framework aims to be a complete package for designing energy-efficient buildings that satisfy building occupants' need in hot climates.

To ascertain the suitability of the proposed framework, the stage three, which involves building design and evaluation was tested through the design of a proposed courtyard house for the study context. The simulation results of the prototype courtyard house showed improvement in indoor thermal comfort and reduction in buildings' energy demand. This confirmed the suitability and relevance of the proposed framework for designing energy-efficient residential buildings in hot climates, especially in the study context. Nevertheless, the simulation results showed that mechanical cooling systems are required to achieve thermal comfort in buildings.

8.0CHAPTER EIGHT: CONCLUSION

8.1 Introduction

This chapter presents the general summary of the whole thesis. It is a conglomeration of the research findings from the literature review in chapter two and the development and testing of the proposed framework in chapter seven. Section 8.2 presents the summary of the main research findings from the varieties of research methods adopted. Section 8.3 discusses the achievement of the aim of the research and the four research objectives. Section 8.4 focuses on the limitations that arise from the conduct of the research. Section 8.5 centers on the research contributions to knowledge while section 8.6 outlines the major research recommendations. Section 8.7 presents suggested areas for future research. Section 8.8 concludes this chapter with a summary.

8.2 Summary of the main research findings

Sustainability and sustainable architecture which provides the basis for energy-efficient buildings were defined in chapter two based on existing literature in relation to the study context. Sustainability and sustainable architecture revealed a strong link between people's need, the natural environment, and buildings. Hence, this research aimed to produce a framework for designing energy efficient dwellings satisfying social-cultural needs in hot climates. The proposed framework was developed in line with the research objectives in outlined in chapter one based on the research questions. The framework was informed mainly by the interviews conducted with 12 design professionals and the interview questionnaire with 72 householders in the study area. Hence, it captures the views of both designers and building occupants who are very relevant to the design of buildings. The framework is expected to guide and encourage building users, architects and other design professionals and government to key into sustainable design principles towards sustainable building development, especially in Benghazi, Libya.

It would be difficult to achieve energy efficient buildings without first identifying the factors that determine the level of energy consumption in buildings. Hence, the researcher identified some of these factors, which include climate, building form, building orientation, building materials, building envelope, buildings occupants' behaviour, lighting systems, ventilation systems and building design.

An exploratory case study on a typical villa in Benghazi was conducted to clarify the research problems identified in chapter one and to provide the basis for the validation of research findings. The survey method adopted involved questionnaire survey of 72 householders, semi-structured interview with 12 design professionals alongside measurements and observational survey, which were conducted during summer time in 2016. Quantitative data were analyzed using Excel while qualitative data involving interviews with householders and design professionals were analyzed using content analysis. Moreover, DesignBuilder was adopted for the modelling and dynamic thermal simulation of an existing villa with a major focus on indoor thermal comfort and energy performance. These processes aim to satisfy the first and second research questions related to how to designers can produce buildings that satisfy socio-cultural factors based on the local climate and the relevant design principles for achieving energy efficient residential dwellings in hot climates.

Socio-cultural factor is an important element of the design of energy efficient buildings. Hence, the researcher proposed a prototype courtyard house, which incorporated important social and cultural norms of the people of Benghazi. The prototype courtyard house was necessary to test the proposed framework for design energy efficient dwelling satisfying socio-cultural needs in hot climates. The model highlighted relevant energy efficiency of design strategies including courtyard design, which can serve as solutions that can be applied to individual houses and at the entire urban scale. Furthermore, the proposed model is expected to serve as a baseline, which can be adopted by designers for the design of energy efficient residential buildings in hot climates. The prototype courtyard house was modelled and simulated using DesignBuilder to determine its performance. The dynamic simulation of the prototype model showed improvement in both indoor thermal comfort and energy demand. The results confirmed the relevance of the proposed framework for achieving energy efficiency in residential dwellings in hot climates. The prototype courtyard house was meant to fulfil the second research question on how the design of energy efficient residential buildings for hot climates can be tested for its performance.

This section of the thesis centers on the summary of the research findings from this study. These are outlined below based on the various data sources.

8.2.1 The main findings of observation and questionnaires

Findings indicated that:

- Householders were highly interested in and value social life in the community.
- Householders have a similar view on a relationship with neighbours, privacy among members of a household and visitors and security.
- Most respondents agreed that the downward trend in cohesion among families and the entire city was due to change in lifestyle patterns and modern approach to housing designs, which have little consideration for socio-cultural factors.
- Majority of householders preferred detached villa in modern designs. The floor layout of the villa should be divided into private, semi-private and semi-public areas to satisfy the privacy requirements of building users. The private functional spaces should be located on the first floor while the ground floor should incorporate semi-private and semi-public areas. The findings showed that most respondents do not like flats and high-rise residential dwellings as they argued that such building types are not appropriate for their cultural life.
- There were challenges with the design of existing contemporary dwellings. This includes the provision of large windows, which were hardly used due to privacy issues. These windows are sources of heat gain and glare, especially during the summer months.
- Windows were covered with thick drapes almost throughout the day to enhance privacy. This greatly reduces daylighting leading to too much dependence on artificial lighting even during the day.
- Most outdoor open spaces were abandoned due to privacy requirements, which is a strong factor in the design of residential dwellings in the study context. The most challenging privacy requirements are between a particular house and their neighbours. Hence, adequate privacy must be provided to encourage the use of outdoor places.
- Findings from householders revealed that most residential buildings were designed by civil engineers. This might be the reason why most of the houses visited lack basic architectural principles. For example, lack of proper orientation, inappropriate size, and location of openings and the provision of balconies. Thus,

it is strongly recommended based on the survey that architects should be made to design houses and not civil engineers or other non-professionals.

- Measurements and observational survey of existing buildings showed that area of functional spaces is too large resulting in a corresponding in the total floor area of dwellings. This has marked effect in the number and/or size of air conditioners required for cooling interior spaces leading to an increase in energy consumption.
- Residential dwellings depended solely on mechanical cooling systems for thermal comfort, especially when there is a supply of electricity from the national grid. During the blackout, most householders prefer to go outside into the outdoor open spaces to relax and receive fresh air. This emphasises the need for proper outdoor open spaces for the householders. It was difficult for householders to stay indoor during the blackout as they rarely achieve desire comfort due to challenges with the design of buildings and privacy requirements.
- Despite the level of clothing for women was higher than men, women were comfortable at a higher temperature than men.
- There is high-energy consumption by houses caused mainly by the use of ACs; it was revealed during the survey that all the respondents use ACs in their houses. Majority of the householders use ACs for 24 hours a day during the summer period. The Higher capacity of ACs (BTU), more than necessary were extensively used in houses, especially in the guest and living rooms leading to high-energy consumption. Further, people depended so much on artificial lighting using incandescent bulbs, which consumes a lot of energy. Excessive use of ACs and artificial lighting has a significant effect on energy consumption. The average monthly energy bills for the 72 houses surveyed is approximately 150 LYD, which accounted for nearly 122kWh/m^2.

8.2.2 The main findings from interviews with design professionals

The findings from the interviews with architects and civil engineers in the Benghazi revealed relevant information regarding this research. These are summarized below:

- It was agreed that sustainable houses could be achieved through social and climatic design principles.

- Western architecture has both a positive and negative effect on Libyan architecture. The negative impact is majorly in terms of lack of consideration of climatic conditions, social-cultural factors.
- Contemporary dwellings do not provide adequate privacy between family and neighbours. This is very important, as some householders have abandoned certain aspects of contemporary buildings on the ground of lack of proper privacy.
- The contemporary housing cannot provide adequate thermal comfort for householders without the use of mechanical cooling systems.
- Respondents agreed that traditional houses are more environmentally friendly than contemporary houses. One of the reasons pointed out was that traditional houses were design based on the local climate.
- To improve privacy, there is the need to design houses around an appropriate courtyard.
- All professionals agreed that sustainable houses could be encouraged in the study context through the adoption of social and climatic design principles. Moreover, the respondents agreed that it is important to adopt some elements of local vernacular architecture and traditional house to enhance privacy and thermal comfort in future housing developments such as a courtyard.
- The approach to the design of houses by architects and civil engineers differ. While architects lay emphasis on design principles, civil engineers lack information on how to design houses using some basic design principle like orientation and adequate privacy.
- Design professionals suggested that future housing development in Benghazi should demonstrate excellent understanding and application of socio-cultural factors, be eco-friendly with the adoption of green energy resources. Moreover, they encouraged the application of modern technology and the use of available local building materials that could enhance energy efficiency in buildings.

- All the professionals agreed with householders' views regarding the consideration of socio-cultural factors, which include privacy and family cohesion in the design of residential buildings.

8.2.3 The main findings from a simulation study of an existing villa

A simulation study is one of the methods adopted in this research. A typical contemporary Benghazi house (villa) was chosen as a case study to determine its performance, especially in terms of comfort and energy consumption. Improvement measures were then conducted on the case study building in terms of orientation, windows, external walls, ground floor slab, roof, and lighting. The improvement measures were carried out in terms of both operative temperature and energy consumption to determine possible savings. The simulation results for both the existing case study and the improved case study revealed important findings of residential buildings in Benghazi. The following are some of the findings from the simulation results using both natural ventilation and mechanical cooling systems.

The simulation of the case study building using natural ventilation showed that

- No functional space in the case study building met the minimum daylight factor of 2%. Hence, the need to improve daylighting in existing buildings.
- Operative temperatures from the months of October to April are within the comfort limit for the study context. This shows that people will be comfortable during this period in their dwellings.
- The lowest and the highest operative temperature were 27.91^{0}C and 32.18^{0}C in May and July respectively. Hence, thermal comfort cannot be achieved in buildings during this period of the year with mechanical cooling systems.
- The total annual energy consumption using natural ventilation was 24,977.79kWh while the major energy consumption for the dwelling was for artificial lighting at 21407.56 kWh.

The following were some of the findings from the simulation results using mechanical cooling systems, split unit ACs.

- The building achieved thermal comfort requirement as comfort set of 25^{0}C. The lowest operative temperature in the month of April at 22.22^{0}C while the highest operative temperature was for July at 26.48^{0}C.
- The total energy consumption using mechanical cooling was 54,009.83kWh, which is almost twice the energy consumption in the building using only natural ventilation. The highest energy consumption for the case study building was due to cooling load at 32143.38kWh.
- It is difficult for building occupants to be comfortable using natural ventilation only
- Excessive use of artificial lighting both day and night accounted for high energy consumption in buildings.

The simulation of the improved case study based on individual and all parameters showed the following findings.

- Rectangular building form elongated towards the east-west axis performed better than other shapes. This might be because it allows for more solar heat gains on south external surfaces in winter and minimum gains in summer.
- The simulation results in terms of operative temperature for individual parameters showed the following findings:
  - The best orientation for the improve case study was 90^{0}E. This orientation decreased the annual operative temperature by 0.03^{0}C.
  - Double glazing clear glass (Dbl Clr 6mm/6mm air) with 500mm wide local shading decreased the operative temperature in July by 2.83^{0}C.
  - External insulated wall of 325mm thick decreased the operative temperature in July by 2.87^{0}C.
  - On-ground floor slab led to a decrease in operative temperature in July by 0.22^{0}C.
  - Roof insulation reduced the operative temperature in July by 3.15^{0}C.
  - Lighting using LED bulbs decreased the operative temperature in July by 3.56^{0}C.

- The simulation results for the improved case study based on all parameters showed an approximately 5^0C reduction in terms of operative temperature in July.
- The annual simulation results in terms of energy demand for all parameters showed the following findings:
  - The best orientation for the improved case study was 90^0E. This orientation decreased the annual demand by 0.02%.
  - Double glazing clear glass (Dbl Clr 6mm/6mm air) with 500mm wide local shading decreased the reduced the annual energy demand by 20.9%.
  - External insulated wall of 325mm thick reduced the annual energy demand by 33.8%.
  - On-ground floor slab reduced the annual energy demand by 11.2%.
  - Roof insulation decreased the annual energy demand by 34%.
  - Lighting using LED bulbs reduced the annual energy demand due to lighting by 44%.
- The improved case study simulation with all parameters showed 84% savings in terms of energy demand.

The findings from the simulation results of existing building, improved case study and the prototype courtyard design based on natural ventilation showed that:

- Compared with the existing building and the prototype design, the improved case study performed better in terms of both operative temperature and energy demand. This is despite the fact that the total floor area of the improved case study is more than that of the prototype courtyard design.
- Despite the improvement recorded for the improved case study in terms of thermal comfort, it did not meet the privacy and other socio-cultural requirements for study context. Whereas the prototype courtyard design did not satisfy comfort required using natural ventilation but met privacy demand by building occupants and can improve family cohesion among other benefits. Socio-cultural dimension is an important principle in sustainable buildings concept. Hence, it might be difficult for building users to be satisfied building

that achieved energy target but failed to satisfy occupants' requirements. Therefore, the prototype courtyard design was preferred for the study context despite its lower energy saving capacity.

- There is a need for the use of mechanical cooling systems in the prototype courtyard design because it did not satisfy comfort requirement for the study context.

Findings from the simulation results of existing building, improved case study and the prototype courtyard design based on mechanical cooling systems revealed that:

- The existing building did not achieve the operative temperature range in the study context at comfort set point of 25^0C. however, the improved case study and the prototype design achieved the thermal comfort requirement using mechanical cooling systems at comfort set point of 25^0C.
- The simulation results seem to confirm that mechanical cooling systems are required for thermal comfort in buildings in the study context.
- The savings in terms of energy consumption using energy efficient design principles for the improved case study (84%) and prototype courtyard design (65%) indicated the importance of energy efficient design in improving thermal comfort and reducing energy demand in buildings.

Comparing with an existing and improved case study, the prototype courtyard design provides more natural lighting inside the building, especially in the living room.

8.3 Achievement of the aim and objectives of the research

The main aim of this thesis was to produce a framework for designing energy efficient dwellings satisfying socio-cultural needs in hot climate using Benghazi context. The research outcome aims to bridge the gap between academic research and architectural practice. Thus, the findings are expected to enhance the approach to the design and construction of residential buildings in hot climates, especially in the study context. Four objectives were identified in chapter one to guide the conduct of this research based on the research questions. This section presents how the research objectives were realized through the research process.

Objective 1: **To assess socio-cultural issues in contemporary private dwellings in Benghazi, Libya.**

To achieve this objective, a critical review of the literature was conducted regarding sustainability, sustainable architecture, and energy efficient buildings and their links to socio-cultural factors in hot climates, especially in Benghazi. Privacy is a major factor in the design of residential dwellings in the study context. Hence, the literature review further explored privacy in terms of thermal comfort and energy demand for buildings in hot climates. Moreover, the literature review presented discussions on the factors that affect energy consumption in buildings by identifying relevant design and construction specification for hot climates.

A literature review of Benghazi, the study area was conducted in addition to measurement and observational survey of existing buildings for a clearer and robust understanding of the main challenges in terms of privacy and other socio-cultural factors.

Objective 2: **To evaluate the energy performance and environmental human comfort in extremely hot domestic dwellings in Benghazi, Libya.**

The second research objective was to evaluate the energy performance of existing residential dwellings in Benghazi. To achieve this objective, the researcher decided to investigate the existing residential buildings through different research methods for a proper understanding of the challenges with housing development in the study context, how to minimise these challenges.

Measurement and observational survey were conducted on 72 residential dwellings for a broad understanding of climatic variables, buildings materials, and construction techniques and their influence on thermal comfort and energy consumption. Moreover, 12 design professionals in the study context were interviewed to provide data on important factors regarding the building development. This includes the approach to the design of buildings, effects of a socio-cultural factor in the design of residential dwellings and possible ways of achieving energy efficiency in buildings.

In addition, a detailed case study of a typical villa was conducted for a robust understanding of the energy performance and indoor thermal comfort in residential dwellings in Benghazi. The simulation study conducted on the selected case study, which was presented in chapter six of this study, provided important findings of residential buildings in the study context.

The finding from the various research methods adopted provided data to support the research progress towards the realization of the research aim and the production of the proposed prototype courtyard house.

In addition, interviews with professionals, visiting and questionnaire with residents in the study area, on the current approach to the design of residential buildings in terms of thermal comfort and energy efficiency. Moreover, measurements and the observational survey were required to authenticate the opinions of householders, especially regarding building design, thermal comfort, energy demand and consumption in residential buildings.

The research objective one was realized in chapters five and six of this thesis. The findings from the research methods adopted established the level of thermal discomfort and energy consumption in residential dwellings. The major causes of thermal discomfort and energy high-energy demand in buildings are due to design approaches and building occupants' behaviour. Design professionals agreed that intelligent design based on privacy and other socio-cultural needs of the people could decrease energy demand and enhance thermal comfort in buildings.

Objective 3: **To produce a framework for designing energy efficient dwelling in a hot climate.**

This objective focused on achieving the research aim, which is to produce a framework for designing energy efficient dwellings satisfying socio-cultural needs in a hot climate. The achievement of objective 1 and 2 led to the production of the proposed framework. Hence, this research objective was achieved in chapter seven. The proposed framework was produced based on the strategies for designing energy-efficient residential buildings, which were revealed by the research methods adopted in this study.

The proposed framework, which consists of three major stages, aims to encourage design professional to design of energy efficient residential buildings in hot climates, especially in Benghazi, Libya.

Objective 4*:* To produce a prototype design for future contemporary housing development in Benghazi by using the framework.

The fourth research objective was to test the proposed framework by designing a prototype courtyard house which is expected to serve as a model for future contemporary residential buildings in hot climates, especially in Benghazi, for energy efficient residential buildings for the study area. This research objective was realised in chapter seven of this thesis.

The prototype courtyard design was developed based on all research findings from literature review, field investigation and case study of an existing villa using dynamic thermal simulation. Moreover, the design of the prototype house was guided by the processes outlined in the proposed framework. The model highlighted relevant energy efficiency design strategies including courtyard design, which promises to provide solutions that can be applied to individual houses and the entire urban scale in the study context.

The simulation results of the prototype courtyard design showed a significant reduction in energy demand and improvement in indoor thermal comfort. Furthermore, the prototype house met socio-cultural needs in the study context compared to the case study villa. The achievement of this research objectives confirmed the realization of the entire research goals.

8.4 Limitation of the study

This research is significant, and it could help to promote energy efficient residential buildings in hot climates, especially in the study context. Nevertheless, there are some limitations associated with this study. These limitations are listed below to guide other researchers in the conduct of the similar investigation.

- There are limited research data on building development in Libya, especially in Benghazi, the study context.

- There were some hindrances to data collection due to socio-cultural challenges. The researcher was not given free access to respondents. For instance, the researcher was not allowed to speak with respondents without being accompanied by a third party.
- The data collection was affected by the crisis in Libya. It was difficult to collect data from some locations while it was impossible to access other locations due to security issues. Blackouts in some dwellings affected the process of data collection, especially for air-conditioned spaces. Some householders refused to give the researcher access to their buildings on security ground due to the crisis.
- The design strategies for achieving energy efficient residential buildings in this study focused on the whole building envelope, building orientation and the building microclimate. Hence, it was difficult to conduct an elaborate study on each element of the building envelope and other factors investigated. The researcher hoped that in-depth study on an individual of few elements would reveal more data on design principles for achieving energy efficient residential buildings.
- The researcher had a plan to contact design professionals on energy-efficient residential buildings for their opinions on the proposed framework, especially those who are familiar with hot climates. However, this could not be achieved through financial challenges and time constraints. Nevertheless, the prototype courtyard house confirmed the relevance of the proposed framework for designing energy efficient dwelling satisfying socio-cultural needs in hot climates.

8.5 Contribution to knowledge

The conduct of this research and research output revealed some contribution to knowledge in the field of energy efficient buildings, especially in hot climates like Benghazi. The key contribution to knowledge, which was identified by the researcher is presented in this section under theoretical and empirical contribution.

8.5.1 Theoretical contribution

- The main contribution is, achieving successful building performance; this study specified the key factors in terms of both energy efficiency and resident satisfaction.
- The major contribution to knowledge is the production of the framework for designing energy efficient dwellings satisfying socio-cultural needs in hot climates. The framework can be adopted as a tool for policy making regarding the design of residential buildings in Benghazi. The framework could serve as reference point for both academic and industry-based research on energy-efficient residential buildings.
- The review of existing data on building development and energy efficient buildings showed a lack of research data in these regards in the study context. Hence, this study will no doubt help to bridge the research gap on building development and sustainable architecture, particularly on thermal comfort and energy consumption in residential buildings.
- Literature review and primary research on the study context showed that courtyard, which is a strong element in the design of buildings, especially in traditional architecture is the best modifier of indoor temperature. However, the simulation study of courtyard design for the study context revealed that courtyard design is not the best modifier of indoor temperature. Hence, this study showed that the adoption of courtyard approach alone is not adequate for regulating buildings indoor climate.
- The design strategies for energy-efficient residential buildings in hot climates, which have been revealed in this study for the study context can be adopted in similar climates for promoting sustainable architecture.
- This study has shown that achieving sustainable architecture through energy-efficient design strategies, which has been adopted in developed countries, is possible in developing countries and cities like Libya and Benghazi.
- This study adopted a mixed method involving interviews, case study, measurement, observational and questionnaire survey. This unique research approach could serve as a model for other researchers for an investigation involving energy efficient residential buildings in similar or other climates.

8.5.2 Empirical contribution

- This research will raise awareness on energy efficient buildings, which can help to reduce energy bills, improve indoor thermal comfort among other benefits.
- Rectangular building form elongated towards the east-west axis performed better than other shapes.
- The individual parameters which were used in this research can reduce operative temperature and energy demand as following:
    - The best orientation for the improve case study was 90^0E. This orientation decreased the annual operative temperature by 0.03^0C and the annual demand by 0.02%.
    - Double glazing clear glass (Dbl Clr 6mm/6mm air) with 500mm wide local shading decreased the operative temperature in July by 2.83^0C and the annual energy demand by 20.9%.
    - External insulated wall of 325mm thick decreased the operative temperature in July by 2.87^0C and the annual energy demand by 33.8%.
    - On-ground floor slab led to a decrease in operative temperature in July by 0.22^0C and the annual energy demand by 11.2%.
    - Roof insulation reduced the operative temperature in July by 3.15^0C and the annual energy demand by 34%.
    - Lighting using LED bulbs decreased the operative temperature in July by 3.56^0C and the annual energy demand by 44%.
- The simulation results for the improved case study based on all parameters showed an approximately 5^0C reduction in terms of operative temperature in July and 84% savings in terms of energy demand.
- The research outcomes could be adopted as a model for the assessment of both existing buildings and future housing development. It offers an approach for evaluating the impacts of climatic factors, building materials, construction techniques and occupants' behaviour on thermal comfort and energy demand in dwellings.
- The research outcomes could be used as a teaching tool on how to design energy efficient buildings, particularly in hot climates.

8.6 Research recommendations

As indicated in other sections of this research has produced and tested a framework for designing energy efficient dwellings satisfying socio-cultural needs in hot climates. The entire research process has revealed some recommendation, which could be relevant to the further investigation of energy-efficient residential buildings in hot climates. These recommendations which emerged from the synthesis of the research findings are presented in this section.

- Experts on the design of energy efficient residential buildings are key to achieving energy efficiency in the building subsector. Hence, there is a need for their involvement in building the development process to improve energy efficiency in buildings.
- Design professionals should key into software tools for building performance assessment for proper prediction of building performance throughout the stages of building design processes.
- Building design approach should strive to achieve a balance between energy efficient design techniques and socio-cultural factors. This could encourage the adoption of energy efficient design strategies by stakeholders in the building sector.
- There is an urgent need, especially in the study context for regulatory authorities to support building performance assessment by increasing statutory requirements for building energy performance, indoor thermal comfort, and other relevant factors.
- To enhance energy efficiency in buildings, building developers should not focus on cost alone but on other variables like energy demand by buildings, comfort requirements and the impacts of buildings on building occupants and the environment.
- Building stakeholders should invest in demonstration projects in energy efficient buildings, which could be a good example for others to follow.
- The government should provide economic incentives through appropriate policies on successful energy efficiency improvements and new build to encourage further investment in this regard.

8.7 Further research areas

This research has discussed the proposed framework, which is the main research output and the prototype courtyard design that confirmed the applicability of the framework. Hence, the study has helped to advance research on energy efficient buildings, especially in hot climates. Nevertheless, there are other areas relating to this study that require further investigation. These areas are hereby identified and suggested for future research.

- As stated earlier, this study has produced a framework for designing energy efficient dwelling satisfying socio-cultural needs in hot climates and tested the framework using computer modelling and simulation. However, there is a need for a demonstration project to serve as a practical application of the principles identified in this research. This is also necessary to compare the performance of the virtual model with the physical building.
- It can be used CFD method (Computational fluid dynamics) which is examining fluid flow in accordance with its physical properties such as velocity, pressure, temperature, density for geometric forms such as buildings. Therefore, it is an important to use CFD method in further research for measuring the air temperature and air speed of open spaces around buildings and on external walls.

- Cost is an important factor for promoting energy-efficient buildings. Hence, a detailed cost analysis of a typical energy efficient building for comparison with a similar conventional building. Research in this regard could promote investment in energy-efficient buildings.
- It was difficult to collect long-term climatic data on existing dwellings due to the crisis in Libya at the time of the survey. The research believes full monitoring of indoor thermal environment in the study context could reveal more robust data on existing buildings. Hence, it is important for future research to consider the adoption of research methods involving long-term monitoring of existing houses.

8.8 Chapter summary

The main aim of this research was to develop a framework that would guide design professionals to design energy efficient residential dwellings satisfying socio-cultural needs in hot climates like Benghazi. The study adopted mixed method approach involving measurements, observational survey, interview with design professionals, and a questionnaire survey with householders and simulation study of an existing villa to identify the relevant variables for producing the proposed framework. The proposed framework was produced based on all the research findings from the methods adopted and tested using a prototype courtyard design for its applicability in chapter seven. The findings from the simulation results of the prototype courtyard design confirmed the usefulness and the relevance of the proposed framework.

To achieve energy efficiency in buildings, there is a need for design professionals to adopt the proposed framework to enhance energy efficiency in buildings. Hence, the study suggested the framework and made other recommendations for promoting energy efficiency in residential buildings in hot climates, especially in Benghazi, Libya.

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Appendices

Appendices A: The Questionnaire Form

I would like to express my thanks and appreciate your time for anticipating and completing this survey. All information provided in this form will be confidentially and professionally employed for the purpose of this PhD study on developing an architectural conceptual design model for new housing sustainability in Benghazi.
Could you please complete all the following questions, for further queries please contact the researcher on the following links?
Email: Nagah_alsharif@yahoo.com Telephone No. +447514201817
Facebook Account: Nagah Alsharif

General Information

- Gender ☐ Male ☐ Female
- Age ( )
- The number of males and females in your family? ☐ Males ☐ Females
- What is your level of education?
  ☐ Undergraduate ☐ postgraduate Other---------------------------------

House information

1. **1.** Who designed your house?
   ☐Architect ☐ Civil engineer ☐ Contractor ☐ Repeater design ☐ Do not know
2. How many floors does it have? --------------- floors
3. What is the area of your property? ---------------m2
4. What is the area of your house?
   Ground floor = -------, First floor =------, Second floor =-----, Third floor =------ (m2)
5. How many openings and balconies does your house have in each façade (exterior walls)? (Window = W) (Door = D) (Balconies = B)
   North facade ☐ W ☐ D ☐ B

   East facade ☐ W ☐ D ☐ B

   West facade ☐ W ☐ D ☐ B

   South façade ☐ W ☐ D ☐ B

6. If your house has open space, is it? ☐ indoor ☐ outdoor ☐ both
7. What is the area of open space? ------ m 2

8. What is in your open space?
   ☐ Pool ☐ plants ☐ seating area ☐ fountain ☐ storage ☐ play area ☐ parking

   ☐Other

9. When do you usually use the open space in summer?

☐ Morning ☐ Noon ☐ Afternoon ☐ Night

10. Are you satisfied with the level of privacy in your open space (between your family and neighbours)?

☐Not at all satisfied ☐slightly satisfied ☐ moderately satisfied ☐ very satisfied

☐Extremely satisfied

Please explain

____

11. How many openings does the open space have?

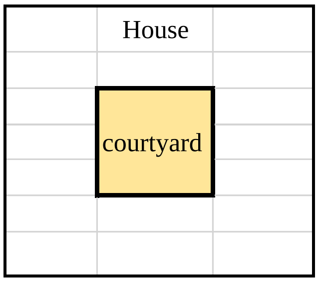
	Window	Door	Veranda
Kitchen			
living room			
Bed room			
Bath room			
Guest room			

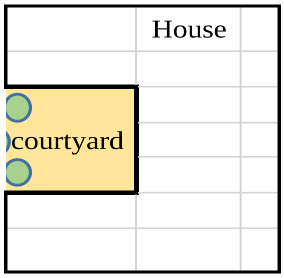
12. Can inner open space help to increase the level of privacy in your house (between your family and neighbours)? ☐Yes ☐ No Please explain _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

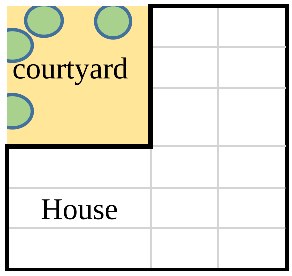
13. Can inner open space help to provide thermal comfort in your house? ☐ Yes ☐ No

Please explain _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

14. Which style of courtyard design do you prefer?







Other

A B C D

Thermal comfort perception

15. Please indicate the room in which you are occupying now in the box (_ _ _ _ _ _)

16. Is air conditioning turned on NOW? Yes No

17. What is the cooling setback temperature do you set up the air conditioning with?

☐ 16 C ☐ 18 C ☐ 20 C ☐ 22 C ☐ 24 C ☐ More

18. What would be the first action you take to escape from high temperature?

☐ Open windows/doors ☐ Change cloths ☐ Escape to another rooms ☐ Going outside house ☐ others please specify---

19 .Please indicate how do you thermally feel now on the scale below

+3 Hot

+2 Warm

+1 slightly warm

0 Neutral

-1 slightly cool

-2 Cool

-3 Cold

20. Could you please indicate how you would like to be now?

☐ Warmer ☐ No change ☐ Cooler

Energy consumption and human behaviour

21. What type is cooling mechanical system in your house? You can choose more than one,

☐ Portable fan Fixed ☐Roof fan ☐ Air conditioning unit ☐ other……………

22. If you use air conditioning, what is the cooling capacity BTU of the unit?

☐ 9,000 ☐ 12,000 ☐ 18,000 ☐ 24,000 ☐ 26,000 ☐ 28,000 ☐ 30,000

☐ Do not know

23. How many of these systems are there in rooms? (A.C.) = air conditioning

	Total number of rooms	Total number of A.C.s
Bed room		
Guest room		
Living room		
Kitchen		
Bath room		

24. In what season(s) is the Air Conditioning system used?

☐ Summer ☐ Winter ☐ Autumn ☐ Spring

25. At what times are they used in summer? Tick all that apply

☐ 24 hours ☐ 6 a.m. to 12 a.m. ☐ 12 a.m. to 6 p.m. ☐ 6 p.m. to 12 p.m.

☐ 12 p.m. to 6 a.m.

26. What is your average monthly electricity bill? (………………….).

Appendices B: Measurement form

Cooled Room								
Room Dimensions (m)	Length		Width		Hight		Paint color	
Room's Area (m2)							Type of room	
Lighting	Type		Power		Brightnees/IIluminance (Lux)			
Room Temperatuer	Air Temperature (Co)		Air Speed/velocity (m/s)		Globe Temperature (Co)			
	Dry-bulb	wet-bulb						
Average								
Type of Clothing	Shorts	Walking shorts & short-sleeve shirt		Skirt, shortsleeve shirt and panty hose		Trousers and shirt	Sweat pants and sweat shirt	
	Skirt, long-sleeve shirt, panty hose and long-sleeve sweater or jacket		Heavy threepiece business suit		Heavy suit and woollen over coat		Others:	
Open space temperature	Air Temperature (Co)		Air Speed/velocity (m/s)		Globe Temperature (Co)			
	Dry-bulb	wet-bulb						
Average								
Direction of open space	N	E	NE	SE	Direction of house	N E	NE	SE
	S	W	NW	SW		S W	NW	SW
Outside temperature	Air Temperature (Co)		Air Speed/velocity (m/s)		Globe Temperature (Co)			
	Dry-bulb	wet-bulb						
Average								

Appendices C: Interview for professional

I would like to express my thanks and appreciate your time for anticipating and completing this interview. All information provided in this form will be confidentially and professionally employed for the purpose of this PhD study on developing an architectural conceptual design model for new housing sustainability in Benghazi.
Could you please complete all the following questions, for further queries please contact the researcher on the following links?
Email: Nagah_alsharif@yahoo.com Telephone No. +447514201817
Facebook Account: Nagah Alsharif

A. Structured interview questionnaires

General information

Please tick the appropriate box below

1. Gender ☐ Male ☐ Female

2. Age group ☐ 20-30 ☐ 31-40 ☐ Above 40

3. Level of education ☐Graduate ☐Post Graduate

   Others (please specify)

   ____

4. Practice ☐Academic ☐ Private ☐ Government (Public)

5. Years of practice ☐1 – 5 ☐ 6 – 10 ☐ 11 – 15 ☐ Above 15

6. From the list below, tick the box as appropriate
   ☐ Architect ☐ urban planner ☐ engineer ☐ project manager ☐ contractor

B. Semi-structured Questions

1-Can the concept of sustainable housing be achieved by social and climatic design? Please explain.

2-Do you think that modern Libyan architecture was influenced by western architecture? And to what extent do these influences contribute to a blurring of development of Libyan architecture?

3-What do you think of contemporary housing in terms of Appropriateness to provide privacy between family and neighbours? Please explain….

4-What do you think of contemporary housing in terms of Appropriateness to provide thermal comfort for family without using air conditions? Please explain…

5-Do you think that the traditional Islamic houses are more environmentally friendly than contemporary houses? Why?

6- In your opinion, what are the elements in traditional dwellings which can enhance the level of privacy?

7- In your opinion, what are the climatic elements in traditional Islamic housing design?

8-Do you think that borrowing elements from local vernacular architecture such as courtyard, openings and orientation could improve the future housing projects in terms of providing privacy and thermal comfort?

This is the end of the interview. Thank you for your time.

Appendices D: Paper publication

A review of Islamic Traditional and Contemporary Dwellings in Hot Climates

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Abstract

In Benghazi, Libya, the rising population and increased housing demand has led to high energy consumption for providing comfortable conditions. These contemporary dwellings employ outdoor open spaces and a high glazing ratio of the building envelope leading to significant underperformance with respect to heat gains and cooling loads when compared with traditional dwellings.

The aim of this paper is to investigate the main features of Islamic traditional houses that can enhance environmental comfort and reveal insights into a comparative study with contemporary houses. The methodology will be by reviewing previous research regarding Islamic traditional houses to find the main climatic features and evaluating contemporary houses in Benghazi, Libya as a case study. Also, distributing 60 questionnaires in terms of determining the main problems which related to residents and housing design for enhancing housing thermal comfort and decrease energy consumption. The comparative study shows that the majority of Islamic traditional houses have sustainable features that can be integrated into contemporary houses to provide thermal comfort whilst minimising energy consumption. These features include internal open spaces (courtyard), small high openings in external façade, together with shading device and building orientation. The research likewise displays the 89% of contemporary Islamic houses in Benghazi not only lack the integration of these sustainable features as internal open spaces but also all of the local residents are depending on air conditioning to face the hot days. Additionally, the survey presents just 15% of architects are responsible for designing these houses, therefore, this led to design windows with a high glazing ratio and locate windows at the hottest facades of houses. The implication of the outcome on sustainable designing of Islamic contemporary houses is discussed to help produce guidelines for designers that would respond to both climate and local people needs.

Key words: thermal comfort, Islamic traditional houses, contemporary houses, and Libya.

1. Introduction

The Islamic religion has a great effect on housing design in traditional dwellings, Islamic society has generated an especial design for houses which the plan of the house was directed into inside with simple façade (external walls) to enhance visual privacy. Furthermore, climate design in traditional houses had a strong role to modify and moderate indoor temperature El-Shorbagy [2]. Also, climate completed the needs of privacy through its design elements, for example, windows were directed to inside into internal open space (courtyard), which help to provide a house with natural light and air ventilation Susilawati, Al Surf [4]. Evidently, the western design was imported to many Islamic countries, for example, in Libya Italian colony established a new housing design in regard to housing development. However, this development has not met the social-cultural requirements of an Islamic country, it has essential principles which should be considered as well as climate conditions Al Sayyed [5]. After 1969, Libyan government started to construct a new and large houses projects to meet the increasing demand for houses without understanding the social-cultural needs and climate conditions in Libya. Although privacy is one of the important requirements in Islamic houses, it is ignored in most of the contemporary houses Nabavi and Goh [7], Mahgoub [7], and Sharif, Zain et al [2]. Furthermore, Khalaf [2], Ajaj, Pugnaloni [2], Khoukhi, Fezzioui [2], and Leylian, Amirkhani et al [5] , indicate that contemporary Islamic houses lacking to climate design elements because there were not studies of the impact of microclimate on the strategy of design process and form of a building.

2. Thermal comfort dimension in Islamic traditional architecture in hot climates

The Islamic traditional architecture displays many of ideas which can be used in present time to help the problems of housing condition in the Islamic countries in a hot climate, the thermal comfort principles will be demonstrated through Islamic traditional houses Ajaj, Pugnaloni [2] .

2.1 Orientation

Sunshine can be defined as a benefit without the damaging effects of extreme temperature and glare. The courtyard house has to do well under the rotation of the sun. In a traditional Libyan house, empirical methods were used to measure the sun projection angles in courtyards. These angles were:

i) The sunbeam angle is the vertical angle between sunbeam and its horizontal shade.

ii) The azimuth angle is the angular distance extending from the sunbeam shade to the north in a clockwise movement, as

Figure 2-5 Different spaces for family according to direction of the sun, Ground floor plan of a home in Diyarbakir, Turkey and Edwards [1] .

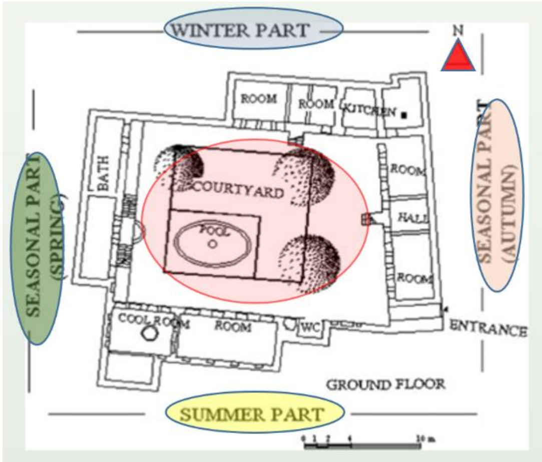

Figure 1: Different spaces for family according to direction of the sun, Ground floor plan of a home in Diyarbakir.

The sun projection angles change at different times through seasons. These provide the degree of solar penetration in many spaces of the house. Therefore, the beast courtyards orientation is the east-west axis and the longitudinal elevation is to the north for the following reasons:

- The sunlight projection is towards the longitude elevation, for example, south.
- The south elevation receives the largest amount of heat in winter and the least in summer Edwards et al [1].

2.2 Natural ventilation

One of the passive cooling strategies in Islamic traditional architecture is natural ventilation. Natural ventilation can enhance indoor climate by evaporative cooling. In addition orientation of traditional houses respect prevailing wind and sunlight, therefore, solid facades are oriented to protect the outdoor living zones from the hot winds simultaneously allowing sufficient winter sunlight to enter the living areas. The main natural ventilation elements with courtyard are wind towers, malqafs. The design of wind towers can encourage airflow in house spaces Bekleyen and Dalkiliç [2]. The different temperatures cause wind circulation. There are differences in temperature between solid and void elements. These elements can cause differences in air density which subsequently leads to the following air circulation:

- Between the interior courtyard and the exterior space.
- Between the courtyard and the interior space of the building.

As a result, the wind is effective in reducing temperatures because of the nature of the use of courtyard architecture. Also, wind-cooling can decrease day-time surface which then benefits night-time conditions Edwards et al [1]. Additionally, for natural lighting and ventilation, openings and windows are essential. However, in summer, the absence of openings help to minimize heat gain, especially on the west side. The openings should be shaded from direct ray and placed high on the walls to be away from ground ray Ajaj and Pugnaloni [2].

2.3 Shading

Solar radiation is a major source of heat gains of a building. Adequate shading decreases air temperature, radiant heat, and glare effectually. Most important ways for shading use protrusions and cornices on outer facades and on the inner courtyard walls Ajaj and Pugnaloni [2]. The amount of shade is determined by the size and shape of the building. In traditional dwellings, there was a large area of shade because some parts of houses had more than one story thus the shaded area increases with the complexity level of housing design Edwards [1]. Also, another important device for providing shading is Mashrabiya which has many significant functions such as:

- Controlling the passage of light,
- Controlling the air flow,
- Decreasing the temperature of the air current,
- Increasing the humidity of the air current, and
- Ensuring privacy.

Also, its design is for filtering the sun and makes beautiful light and shade patterns by changing the sizes of the interstices (spaces between adjacent balusters) and the diameter of the balusters Ajaj and Pugnaloni [2].

3. Contemporary houses problems

3.1 Housing design changes

Traditional houses are often well adapted to climatic and environmental considerations. In addition, they have an evolved to fulfil the socio-cultural dimension. In spite of all these benefits, most of the features of traditional houses have disappeared in contemporary house developments in Islamic countries. Mahgoub [7] pointed to the theory of re-emergence of courtyards in dwellings has shown valid in the architecture of the Islamic countries, which witnessed fast developments and changes since 1950 after the discovery of oil and economic wealth generated by its sales. Many cultural and traditional architectural features were changed by new elements and ways of life Mahgoub [7]. Most Islamic countries, as Libya, have had a fast growth in the economic sector with increasing in population. This change resulted in an increase of building modern houses which influenced by western designs. In other words, designs of modern houses have been changed away from the concept of traditional houses in which the occupants meet their requirements for socio-cultural and environment aspects Al Aali [4]. These contemporary designs are generally seen in high-rise blocks and individual houses Ahmed [2]. The majority of buildings in cities, for example, Benghazi, are from houses, according to SBB residential buildings represent the highest proportion buildings with 40.61%. Most of these houses have modern western ideas which were used instead of many cultural and architectural ideas; for example, outdoor spaces in modern villas were used instead of indoor spaces in traditional courtyard houses, big and glassed windows were used instead of high, small openings and concrete and steel were used instead of the traditional building materials Gabril [4]. During different stages of Islamic countries architectural development, the disappearance of characteristics of a traditional house was a consequence of the transformation of the housing design. Nowadays, the houses are re-oriented to the street and have become less responsive to the residents social situations, privacy, and thermal comfort.

The courtyard houses have changed from privacy where the residents positively utilize the inner spaces that are organized around open and sheltered central space, to an exterior space where inhabitants lose a function and role of the house's spatial form Mahgoub [7]. Most of the outdoor spaces such as balconies, verandas, and gardens, do not use them effectively because they are not providing privacy and became with time non-functional spaces Shawesh [4].

3.2 Energy consumption

El-Shorbagy [2] indicated that climate acts as a complement and moderating factor for society and religion requirements for providing privacy, therefore, it is important to consider the climate role in Islamic architecture El-Shorbagy [2]. Local climate and energy consumption issues are, furthermore, mostly ignored in contemporary architecture design in Islamic housing. A rise in indoor temperature has led to the use of air conditioners strongly, which contributed to an increase in energy consumption for cooling, heating and water heating and CO_2 emissions within the surrounding environment Gabril [4]. According to UN Statistics Division/ CDIAC, in terms of carbon dioxide emissions, Libya was recorded as the 11th country among countries in the world, with 1.98 tonnes per capita carbon dioxide emissions. This is higher than the global average of 1.13 tonnes a year Gabril [4].In addition, because of rapidly growing demand for electric power in Libya, it leads to power shortages widespread in Libya. This demand is increasing fast at a rate of about 6–8% per year. For example, in 2002 demand for electricity was to 13.414 billion kWh while in 2010, it reached to 5.8 GW and expected to reach to 8GW by 2020 Gabril [4].Because of previous reasons there is a need to study, investigate and try to find solutions to reduce the energy consumption, this research will focus on residential buildings because they consume the highest electricity rate among other sectors. According to the General Electric Company of Libya "GECOL", the highest energy consumption is from houses which is used for cooling, heating and water heating with total 39% of total Libya's energy consumption GECOL [7].

4. Aim and methodology of the research

The research investigates contemporary dwellings in Libya, as well to meet inhabitants' needs according to socio-cultural and climatic factors. Contemporary house designs in Benghazi will be used as a foundation for the research, using the results of the study to design sustainable houses for Islamic cities with the same climate. The research will assess how much appropriateness the contemporary Islamic dwelling provide comfort and requirements necessary for residents in Benghazi. In order to achieve the aim and of the research and draw a clear picture for determining and analysing the problems. A multi- method approach is adopted to contextualise this work on comfort and design in hot climates referring to the specific Libyan case context. Necessary information will be reviewed from previous research regard to Islamic traditional houses to find the main climatic features. In addition, Benghazi contemporary houses as a case study will be investigated to determine the main architectural design elements which affect the thermal comfort and increase of energy consumption. To support the need of the research, a survey had been done to determine occupant's opinions of housing comfort and their views towards their general satisfaction the environment perspectives in contemporary private sector housing in Benghazi, Libya. Furthermore, the survey was distributed randomly in two different neighbourhoods (apartments and villas). The size of samples which have been distributed was 60 surveys (30 for apartments and 30 for villas), 51 completed questionnaires and returned where 24 questionnaires from apartments and 27 questionnaires from villas. The survey was divided into five sections which are general Information, house information, house design, house elevations, and cooling demand.

5. Benghazi background

According to the Libya National Statistics Office projections (LNSO), Benghazi has 631,555 populations, leading to the highest population density in the other Libyan cities, 2000 inhabitants per square kilometre Agll and Hamad et al [5]. Benghazi is considered a magnet for the migration of people from different regions of Libya, from the south, east, and even from the west, because of economic prosperity and providing job opportunities. Therefore, this has led to increased population growth and increased demand for housing. According to the National Physical Plan, the yearly demand for housing will grow regularly from 24,000 units to 38,000 units between 2000 and 2025 Mohamed [4].This increase in housing construction offset by an increase in using air conditioning which led to energy consumption and emission of carbon dioxide. According to the General Electric Company of Libya (GECOL), houses in Benghazi are responsible for a majority of energy consumption. Residential buildings consume energy with 36% in 2012 GECOL [7]. Beside houses in Benghazi lack to be considered in regards to climate conditions also, they lack to the provision of social requirements such as privacy between resident and neighbours despite their high cost on building outdoor gardens Al-Jamea [5]. Therefore the needs for study, how can apply the concept of society and environment sustainability of housing in Benghazi, is necessary Almansuri [5]. In Benghazi, contemporary house types can be classified into two different models; apartments, and private houses (terraced houses, villa). According to the National Census (NSA) and the Benghazi Planning Study, El- Emara Engineering Consultants, the majority of houses are private houses (villas and terraced houses) with 60.50% percentage, villas are preferred from most people in Benghazi Mohamed [4]. Benghazi dwellings have distinguished exterior form without considering on interior spaces and relation between outdoor and indoor and orientation. For instance, windows are directed to outdoor space rather than to indoor space (courtyard) as fig 2, the courtyard was working as a centre for family life and a climatic control. Subsequently, air conditioning is used instead mashrabiya which can reduce solar radiations with cool ventilation because it is an enclosed window with an engraving wood lattice formed and located on the second floor of a building. In addition, the mashrabiya had another role beside to a climatic role which is providing privacy to residents. Furthermore, the design of modern houses allow a greater amount of solar radiation to enter through the exterior facades (large glazed windows) without considering about the best orientation, this is the type of design is not appropriate to the climate of Benghazi. Thus, windows in Benghazi houses has two negative impacts socially and climatically. In addition, many verandas and balconies in current houses were closed or used for storage or not used, because the balconies cannot provide privacy required to residents in both types of dwellings (apartments, villas).

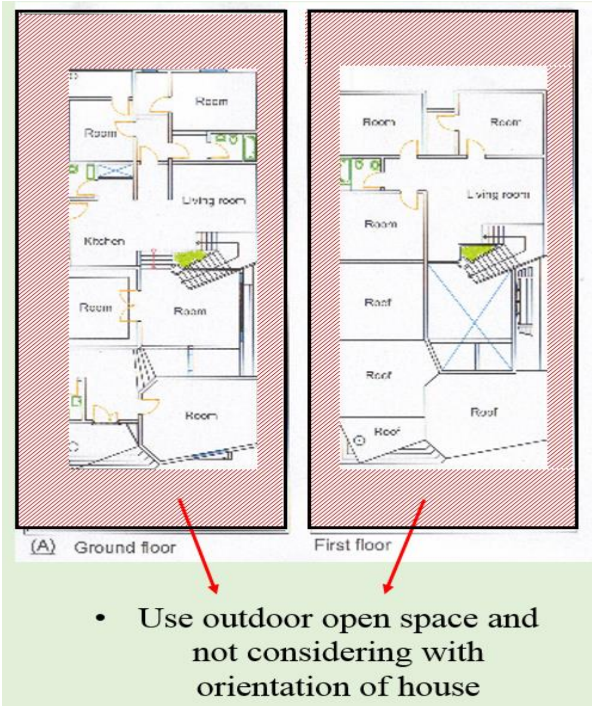

Figure 2: Plan of private house with outdoor open space surrounding the

6. The main findings

6.1 House design

6.1.1 Open spaces

Regarding the location of open spaces in villas (indoor, outdoor or both), 89% of villas have outdoor open space while 7% have both kinds and 4% have just indoor open spaces. In addition, the type of use of open spaces as fig 4, all open spaces are used for parking, then the highest percentage of uses are for play areas, storage and seating areas with 85%,78%, and 74% respectively. Plants are not common, just 48% have plants in their houses while pools and fountains are not existing. Therefore, outdoor space cannot play the same role of internal space of traditional houses for providing a comfortable domestic place for families with acceptable climate.

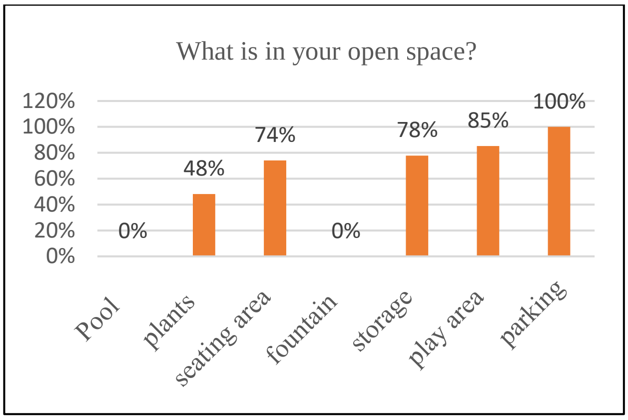

Figure 4: Usage type of open spaces

According to the time for using the open spaces, the most preferred time is the afternoon with 81%, whereas, no one is using the open space during noon time because the hot climate in outdoor space does not allow residents to use outdoor space effectively. Therefore, the most residents are using outdoor open spaces for parking and storage place.

6.1.2 Openings and balconies

According to question (who design your house?), repeater design and contractor are the main sources to design private houses with 33% and 30% respectively whilst architects are not responsible for designing private house with just (15%). Therefore, the majority of the number of windows are located on the hottest facades which are east and west directions approximately 100 windows on east façades and 94 windows on west façades as fig 5, and this is reflect the importance of the role of architects in designing houses.

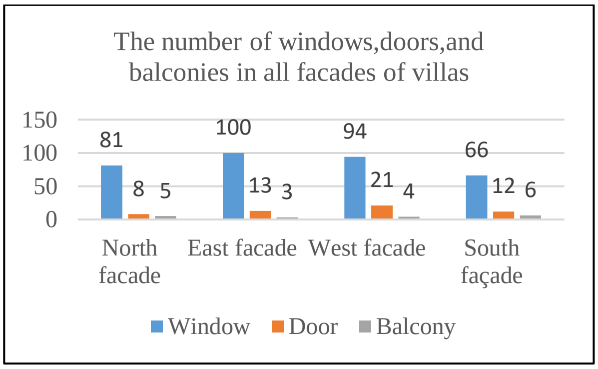

Figure 5: Number of openings and balconies in facades of private houses (villas)

6.2 Cooling demand

According to fig 6, all residents of flats and villas are using air conditioning as a cooling mechanical system. Therefore, it is important to know which the BTU (the cooling capacity of air conditioning) is most using in housing buildings, the result was 18,000 BTU is the common use in flats and villas with 16 and 21 respondents respectively and then 24,000 and 26,000 BTU are the second common uses in flats while in villas, 24,000 and 28,000 BTU are the second common uses. In addition, 30,000 BTU is using in villas with 7 respondents but in flats, it does not use, therefore, the area of house effects on the cooling capacity of air conditioning.

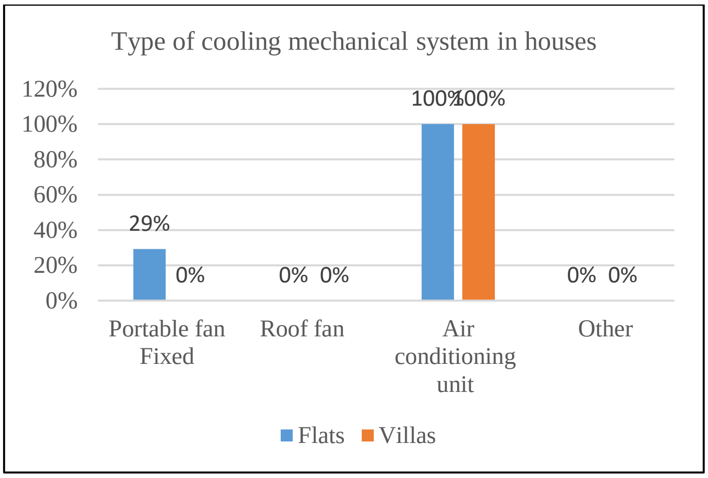

Figure 6: Type of cooling mechanical system in houses.

According to question (in what seasons (s) is the air condition system used?), the highest use of air conditioners is through the summer season in all flats and villas. Also, in villas, air conditionings are heavily used through spring and autumn seasons with 89% and 70% respectively which indicate to increase of air temperature during these seasons.

7. Conclusion

This study concerned with reviewing the main features of Islamic traditional houses that can enhance environmental comfort and reveal insights into a comparative study with contemporary houses in the hot climate of Benghazi, Libya. Also, the study used the questionnaire which was conducted in January 2016 for preliminary data to serve further work that will be continued for full research on these issues, and this work will lead to achieving the appropriate principles of thermal comfort in such hot architecture. The results of this study can be concluded in the following:

1. Taking consideration the courtyard concept of Islamic traditional houses environmentally as an important element in modern design which it can provide an acceptable indoor environment with providing a private family place. In addition, providing ventilation by regulated air movement between internal open spaces and external small openings with providing maximum shading of direct and reflected sun radiation in the hot season.

2. With regard to the architectural issues in Benghazi housing, the contemporary private houses have different architectural elements with traditional houses as using outdoor spaces instead to internal spaces and using external large glazed windows instead to high small openings. These differentiations lead to increase indoor temperatures in current houses in Benghazi subsequently, forcing residents to use air condition to reduce temperatures.

3. From the questionnaire results, it can be extrapolated that the majority of houses have outdoor spaces and the main usage of them is storage space because they lack to an acceptable environment.

4. It is important, architects have the responsibility to design houses with contributing the users.

5. Reduction of the heavy usage of air conditionings in private houses, it should consider implementing the traditional elements in contemporary houses in future such as courtyards and openings facades.

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